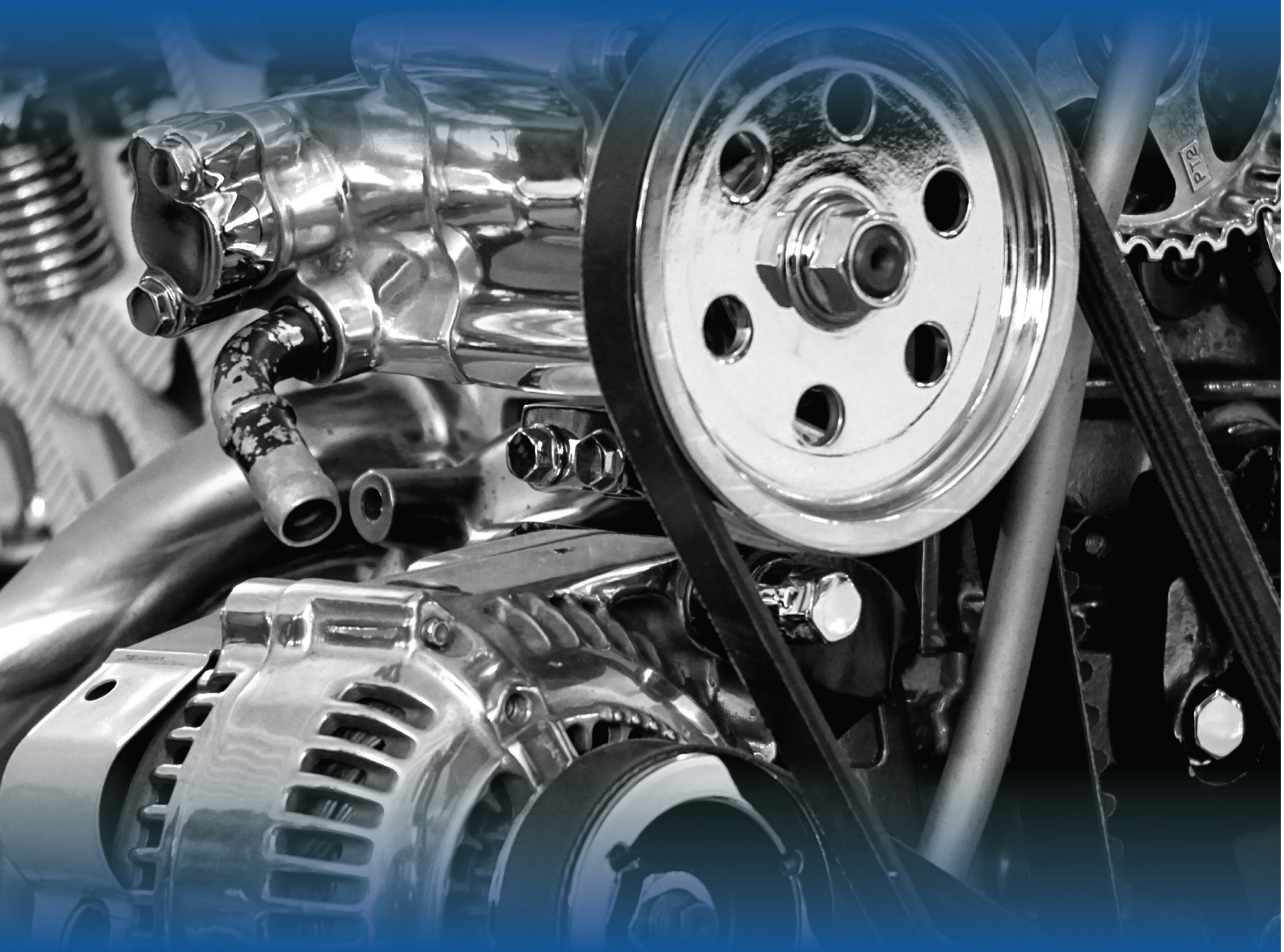


RECENT TRENDS IN MECHANICAL AND AUTOMOTIVE ENGINEERING TECHNOLOGY

**THE 1ST, 2ND, AND 3RD
MECHANICAL ENGINEERING RESEARCH COLLOQUIUM**



**SHAMIL SHAARI
MOHD HAFIZI ZOHARI
AMANINA FARHANA AHMAD**

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Penerbit
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Kuantan
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PREFACE

The 1st, 2nd, and 3rd Mechanical Engineering Research Colloquium are organized by the Faculty of Mechanical and Automotive Engineering Technology, Universiti Malaysia Pahang Al-Sultan Abdullah, Pekan, Pahang, Malaysia. These colloquium events are platforms for researchers to gather, present, and discuss their latest findings in mechanical engineering.

The 1st Series took place on 22 June 2022, followed by the 2nd Series on 18 January 2023, and the 3rd Series on 22 January 2024. Each event brought together academics, industry professionals, and students to exchange ideas and advancements in the field.

The proceedings of these colloquium events include a diverse collection of 27 research articles covering various fundamental and applied topics in mechanical engineering. These topics include material science, structural mechanics, thermal systems, manufacturing processes, and automotive engineering.

These events provided valuable opportunities for networking, collaboration, and the dissemination of cutting-edge research. The success of these colloquium events is a testament to the dedication of the organising committee and the support of Universiti Malaysia Pahang Al-Sultan Abdullah.

We extend our heartfelt gratitude to all participants, keynote speakers, and contributors who made these colloquium events a success. Special thanks to the organising committee for their hard work and to Universiti Malaysia Pahang Al-Sultan Abdullah for their continuous support.

Thank you, and we hope you enjoy the enriching experience of these knowledge-sharing sessions.

Shamil Shaari
Editor-In-Chief

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P01

Numerical Analysis of Internal Channel Geometry in A Cutting Tool

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ABSTRACT

Metal cutting process is often accompanied by heat generation at the contact area between cutting tool and the workpiece. Cutting fluid is used to remove the excessive heat generated and decrease the temperature of cutting tool. The benefits come with several drawbacks as cutting fluids are not environmentally friendly, high cost, and contain hazardous substance which may cause health issues to the workers. Several alternatives to conventional flood cooling have been proposed such as internal cooling channel embedded in the tool holder. This work focused on the Computational Fluid Dynamics (CFD) modelling to evaluate the flow regime in the cooling channel to improve the cooling performance of the cutting tool. In this work, the determination of flow regime, and the evaluation of pressure drop have been done. The fluid used in this analysis is assumed as a Newtonian, incompressible, single-phase fluid. The result of the work will determine the appropriate pumping capacity for the system and the values obtained from the calculations can be used to evaluate the performance of the cooling channel in heat removal during machining process.

Keywords: Flow regime, internally cooled cutting tool.

INTRODUCTION

Machining industries use a considerable amount of cutting fluid especially for reducing cutting tool temperature. The importance of using cutting fluid in machining process is that approximately 90% of the mechanical energy during metal cutting process is converted to thermal heat flux, which causes cutting temperature to rise (Pervaiz *et al.*, 2018). Traditionally, machining process make use of cutting fluid by dousing it to workpiece. While this practice has a lot of benefits in the machining process, it poses negative impacts towards the environment, machine operators, and the economics of the produce (Sprince *et al.*, 1997; Isik *et al.*, 2017; Li *et al.*, 2017).

With increasing environmental awareness, there has been an increasing study towards innovative machining cooling techniques by applying internal cooling system to replace the traditional cooling technique of dousing the workpiece in cooling fluid to remove the heat generated from machining process (Singh & Sharma, 2022).

The current work is focusing on the Computational Fluid Dynamics (CFD) modelling of the internal flow inside the cooling channel (**Table 1.1**) to evaluate the flow regime in the cooling channel to improve the cooling performance of the cutting tool. In this work, the fluid is assumed to be Newtonian, incompressible, single-phase fluid. From this work, the proper pump capacity can be determined, and the values obtained from the calculations can be used to evaluate the performance of the cooling channel in heat removal.

This study will utilise the theories of fluid dynamics and heat transfer. In a system with a fixed quantity of matter, it must follow the law of conservation of mass as in equation (1):

$$\int_{CV} \frac{\partial \rho}{\partial t} dV + \int_{CS} \rho \vec{V} \cdot \vec{n} dA = 0 \quad (1)$$

Where ρ is the fluid density, $\vec{V}$ is the velocity vector, $\vec{n}$ is the outward normal unit vector (perpendicular to surface area element, dA). On the left-side of the equation is the rate of mass within the control volume (V = volume of fluid). The right-hand side represents the rate of mass flux through a control surface (CS). The study was conducted using an incompressible, single-phase fluid. Equation (1) can be derived into the following equation:

$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho v_x)}{\partial x} + \frac{\partial(\rho v_y)}{\partial y} + \frac{\partial(\rho v_z)}{\partial z} = 0 \quad (2)$$

The conservation of momentum equation is determined based on Newton's second law that states that the rate of change of momentum is equal to the sum of external forces acting on the system. However, it is complicated to elaborate since the stress tensor σ_{ij} contains nine components. For a Newtonian, incompressible, steady state fluid, the equation can be further simplified in the form of Navier-Stokes equation:

$$\rho \frac{D\vec{V}}{Dt} = -\vec{\nabla}P + \rho \vec{g} + \mu \nabla^2 \vec{V} \quad (3)$$

Pressure drops happen due to friction loss inside the channel due to friction from the pipe and the pipe elevation. It can be calculated by using the following formula:

$$\Delta P = f \frac{L}{D} \frac{\rho V_{avg}^2}{2} \quad (4)$$

Where f is friction factor and for laminar flow, it depends on Reynolds number:

$$f = \frac{64}{Re} \quad (5)$$

In turbulent flow, the friction factor is usually obtained from experiments. Moreover, the friction factor for turbulent flow depends on the surface roughness of the pipe wall and it increase with higher surface roughness. A correlation that covers a large range of Reynolds number ($3000 \leq Re \leq 5 \times 10^6$) has been proposed by Petukhov (Petukhov, 1970) is as follows:

$$f = (0.790 \ln Re - 1.64)^{-2} \quad (6)$$

RESULTS AND DISCUSSION

The study was conducted with different inlet velocity ranging from 0.2–3.0 m/s at the temperature of 300K to cover all three types of flow regime. Water is chosen as the cooling fluid due to its availability and environmental friendliness. Furthermore, water have high heat capacity which helps in removing heat, a vital property in any cooling system. At each velocity, the friction factor and the pressure drop were calculated. The result for the calculations is recorded in **Table 1.1**. The results show that that the Reynolds number is distributed in the range of 468.49 to 7027.41.

Table 1.1: Reynolds number, friction factor, and pressure drop inside the channel at different inlet velocity

Inlet velocity (m/s)	Reynolds number	Friction factor	Pressure drop (kPa)
0.2	468	0.1366	0.09
0.4	937	0.0683	0.17
0.6	1405	0.0455	0.26
0.8	1874	0.0342	0.34
1.0	2342	0.0496	0.82
1.2	2811	0.0466	1.12
1.4	3279	0.0442	1.37
1.6	3748	0.0423	1.71
1.8	4216	0.0407	2.08
2.0	4685	0.0394	2.48
2.2	5153	0.0383	2.92
2.4	5622	0.0373	3.38
2.6	6090	0.0364	3.87
2.8	6559	0.0356	4.39
3.0	7027	0.0348	4.94

CONCLUSION

This work demonstrated the fluid flow analysis for water supplied in an internally cooled cutting tool with channel diameter of 2 mm at different velocity ranging from 0.2 – 3.0 m/s. The results show that the pressure loss in the channel is inversely proportional to friction factor. This is crucial to determine the correct pump capability to be used in the experimental setup.

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P02

Prediction of Fitness Levels Based on Physical Activities in Preventing Early Cardiovascular Diseases Among Young Obese Adult

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ABSTRACT

The functionality for an advance technology of wearable devices, such as smartwatch, in preventing cardiovascular diseases can be improved. Although there are lot of smartwatches offering the function of providing health readings, such as blood pressure, heart rate and electrocardiogram, which is closely related to the heart health, there is no clear cardiovascular disease (CVD) risk indicator offered by them. Thus, by optimising all measurements available from the smartwatch, including fitness level, this study aims to investigate the relationship between fitness level and cardiovascular disease and the fitness level potential to be used in the cardiovascular diseases' prediction model. Then, the proposed model will be implemented into the smartwatch's interface and new features can be offered by displaying the percentage of CVD risk after analysing the user's data after a certain period.

Keywords: Predictive model, Cardiovascular Diseases, Fitness Level, Self-Monitoring, Machine Learning

INTRODUCTION

According to the Malaysian National Health and Morbidity Survey (NHMS), in 2019, obesity is an alarming issue with half (50.1%) of Malaysian adults are reported to be overweight or obese, with 30.4% and 19.7%, respectively. A total of 52.6% of adults were found to have abdominal obesity. Non-communicable diseases (NCDs) such as diabetes, hypertension, and heart disease are the major diseases associated with obesity and abdominal obesity. This means that there are higher risks for getting NCDs among obese individuals compared to non-obese individuals. The extreme consequences of obesity, which include fatality, have become a worldwide issue. NCDs in Malaysia account for 67% of premature mortality and over 70% of disease burden in 2014 (NHMS, 2019). Indirectly, obesity is also responsible for premature death in Malaysia as obesity leads to other NCDs (Purnell, 2000). Therefore, this study will be focusing on young obese adults under the range age of 18-35 years old, with an aim to prevent another NCDs, specifically CVD, and premature mortality at an early stage.

CVDs are the leading cause of death in Malaysia. About 8.1% of the Malaysian population are currently living with three major risk factors of CVD which are diabetes, hypertension, and high cholesterol. Meanwhile, 3.4 million people in Malaysia are currently living with two major risk factors of CVD. Malaysia is facing a serious problem in combating these issues as the NHMS also reported that one (1) in every five (5) adults (3.9 million) suffered from diabetes, three (3) in every ten (10) people (6.4 million) have hypertension and four (4) in every ten (10) people (8 million) have high total cholesterol levels (NHMS, 2019).

Physical inactivity is associated with the leading risk factor for NCDs and global mortality (Nauman, et al., 2019). Malaysia is facing another serious health issue, as reported by NHMS 2019, which that one (1) in four (4) adults in Malaysia are physically inactive. Previous study presented that intensive lifestyle modification, resulting with only mild weight loss has been shown to reduce incidence of diabetes by 58% among obese (Huang, et al., 2004). Thus, this study will be focusing on implementing an active lifestyle, a 12-week intervention of cardio exercise to a sedentary, young obese person, monitoring and analysing the changes in fitness level focusing on the heart health, staying true to the study's aim to prevent CVD.

There is a lot of tests used to measure overall heart health such as echocardiogram, electrocardiogram (ECG), magnetic resonance imaging (MRI), CT scan, exercise cardiac stress test (i.e., stress ECG), and cardiac blood test, including lipid profile, protein related test and glucose test (disease that can harm blood vessels). Apart from being highly accurate in general screening for heart disease, these tests seem to be unsuitable to act as self-monitoring CVD risks as they require healthcare providers to do these tests and interpret the results later. Thus, there is a need of friendly-user and easily access method for an obese person used to monitor the progress of CVD risks reduction after they have implemented active lifestyle.

Latest technologies have come out with a lot of wearable technologies and non-invasive gadgets, such as smartwatches, that can be used in daily life. Smartwatches can be linked to the smartphone and make it easier for the users to check on their notification without hustling to get to their smartphone, especially when they are exercising or while charging it. Beyond that, there is also a smartwatch that acts as a self-monitoring health device which offers measurements related to health such as blood glucose, blood pressure, body temperature, oxygen saturation, electrocardiogram, and Vo^2 max.

The issue is that users are having trouble to interpret the results gained from the smartwatches and they need to focus on multiple indicators to identify the CVD risks. Eventually, they might give up halfway as they cannot see the effects directly and statistically. A study by Kim (2019) has proposed a CVD prediction model for high-end smartwatch (Samsung smartwatch) users by using machine learning approach. The model was developed by using blood pressure and fasting blood glucose level, which are currently only offered in high-end smartwatches. Therefore, this study will propose an affordable alternative by exploring the mechanisms of fitness levels based on daily physical activities of young obese adult as an early effort to prevent CVD by adapting the same machine learning techniques, which are logistic regression, artificial neural network, and support vector machine. Fitness levels are available on almost all current smartwatches.

RESEARCH SIGNIFICANCE

By understanding the mechanisms on which fitness levels may influence CVD risk, it can contribute to the development of targeted interventions and strategies to prevent or manage CVD in obese individuals, such as promoting physical activity and improving fitness level. The interventions can include structured exercise programs, lifestyle modifications, and behavioural interventions, aimed at improving fitness levels in obese individuals. Then, the successful evidence-based intervention can contribute to the development of strategies to prevent and manage CVD in obese populations. In addition, fitness level can be a useful predictor of CVD risk in obese individuals, and can be used as a screening tool or a clinical parameter to assess CVD risk in clinical practice by medical practitioners. Therefore, this research proposes a CVD risk prediction model among young obese adult to illustrate the mechanism between fitness level and CVD risks factor. This model will be implemented in the smartwatch interface and will be safe to be used only as an early prevention method and not to be used for diagnosing CVD. Consequently, it will increase the awareness among young adult and decrease the disease burden causes by CVD affected by obesity in future.

CONCLUSION

Numbers of users wearing smartwatches are increasing each passing days and with the advancement of technologies, smartwatch users can use it as self-monitoring device to monitor their health through health-related data such as calories, heart rate, oxygen saturation, sleep monitor and physical activity index. Latest technologies introduced more advance features which are related closely to the heart health, which are electrocardiogram (ECG), blood pressure (BP) and blood glucose, and of course with a higher price. A recent study by Kim (2021) reported that data from smartwatch, which are systolic BP and fasting blood glucose, are important predictor of cardiovascular events. Hence, this study was initiated under the assumption that it would also be possible to predict the prevalence of CVD based on the data available in an affordable smartwatch, without the systolic blood pressure and fasting blood glucose data measurements.

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P03

Research on Free Piston Engine Generator Performance of Use Electro-Magnetic Valve Technologies

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ABSTRACT

This study presents the development of an electromagnetic drive valve mechanism based on a moving coil electromagnetic engine actuator, which has the potential to improve engine efficiency and reduce energy consumption. The proposed mechanism is compared to various cam-less drive valve mechanisms through system scheme analysis, system simulation and design, valve motion control, energy consumption analysis, and system testing. The research findings suggest that the proposed mechanism enables precise control of valve motion, which can lead to improved engine performance and reduced emissions. Overall, this study contributes to the development of new technologies that can improve free piston engine generator (FPEG) efficiency and reduce emissions, and its findings can guide future research in this area.

Keywords: electro-magnetic drive, FPEG, simulation.

INTRODUCTION

In today's society, Yang et al. (2023) pointed out that energy problems are becoming increasingly prominent while environmental problems are becoming more severe. Environmental protection and energy saving have become the main direction of the development of internal combustion engine. The development trend of automotive power plant mainly includes electric vehicle technology, hybrid electric vehicle technology, fuel cell technology, alternative fuel technology and so on.

Hybrid electric vehicle integrates internal combustion engine (Raheem et al., 2022) and a set of auxiliary power system composed of motor and power battery, and carries out power balance, coupling and energy regeneration and storage by this system, which is the main direction of the development of electric vehicle at the present stage. The research of this thesis is based on the demand of air exchange function of free piston engine generator power system applied to hybrid electric vehicles

Cam-less Valve technologies (Hanipah et al., 2022) cancels the camshaft and its auxiliary parts in the traditional valve structure, and replaces it with Electro-Magnetic, Electro-Hydraulic (Porter, 2020), Electro-Pneumatic, and other ways to drive the valve. Theoretically, it can completely control the movement of the inlet and exhaust valve, flexibly adjust various valve motion parameters, and control the inflation efficiency and residual exhaust gas coefficient by adjusting the opening and closing time of the valve to improve combustion and reduce emissions. It can also monitor different load engine throttle control, reduce air loss, improve efficiency.

The valve mechanism (Zibani et al., 2019) without camshaft valve drive has many advantages. It can flexibly and separately control the opening, closing and valve opening duration of the intake and exhaust valves, so that parameters of each engine are in working condition and can meet the best performance requirements and improve the overall performance of the engine. The flexibility of the

valve arrangement may also lead to the design of new combustion chamber forms that are more conducive to engine operation. Each valve is driven separately, so it is easy to sequentially stop the cylinder, so that the engine is in a lower fuel consumption rate working state, reducing fuel consumption. The effective compression ratio of multiple fuel engines can be changed by adjusting the late closing time of intake valve in real time to meet the requirements of different fuels.

RESULTS AND DISCUSSION

In the simulation, the pressure of the gas in the combustion chamber on the top of the valve is ignored. The target valve displacement is given by square wave signal. By changing the period, duty cycle and amplitude of square wave signal, different engine speed, valve opening duration and maximum valve lift are simulated respectively. By combining these modules, a complete electromagnetic drive valve mechanism model can be obtained, which can simulate the dynamic characteristics of the electromagnetic drive valve mechanism and conduct in-depth research on its control strategy (see **Figure 3.1**).

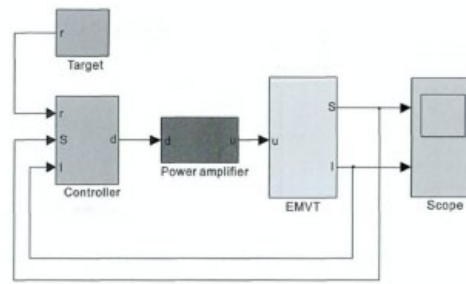


Figure 3.1: Simulation model of electromagnetic driven valve mechanism

Based on the system characteristics of the electromagnetic drive valve mechanism, an overall scheme of piecewise control of valve motion based on inverse system method is proposed. By referring to the system equations of the electromagnetic drive valve mechanism, the inverse system model is obtained, and the FPEG system is established. The state feedback controller and state observer for the FPEG system are designed to carry out the state feedback control for the FPEG system. Then, the proposed control scheme is studied by simulation and experiment, and compared with PID control method, the evaluation index of valve seat performance is proposed, and the characteristics of valve seat are studied in detail from the two aspects of seat speed and seat retention (Lou & Zhu, 2020). The corresponding impact stress behaviour is illustrated in **Figure 3.2**.

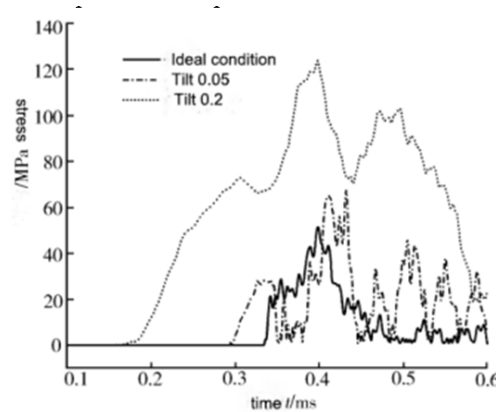


Figure 3.2: Setting impact stress

This study conducted both simulation and system tests to evaluate the performance of the electromagnetic drive valve mechanism. The working process curves of the mechanism were obtained through testing and analysis under different operating modes. In addition, the mechanism was integrated into a FPEG system for system testing, which further verified its working stability and feasibility.

Finally, experiments were conducted to verify the flexible adjustment ability of valve operating parameters of the electromagnetic drive valve mechanism, and the results were compared and analysed against those of different variable valve mechanisms. Overall, the study provides valuable insights into the performance of the electromagnetic drive valve mechanism and its potential for improving FPEG system efficiency and reducing energy consumption (Akal et al., 2019).

CONCLUSION

This study shows that the electromagnetic drive valve mechanism can greatly improve the gas passing ability of FPEG at low speeds and can achieve similar performance to cam-driven valve mechanisms at high speeds. It is feasible to replace the cam-driven valve mechanism with the electromagnetic drive valve mechanism for engine air exchange functions. In integrated power systems of internal combustion and engine power generation, the electromagnetic drive valve mechanism can achieve stable and reliable air exchange functions, which lays the foundation for further applications in conventional engines. The mechanism can also flexibly adjust all valve operating parameters, including valve timing, maximum valve lift, transition time, and valve opening duration, and has greater potential to improve FPEG performance compared to other variable valve mechanisms. Through comprehensive testing and evaluation, the study verifies the electromagnetic drive valve mechanism's system scheme and control strategy and confirms that the prototype meets design requirements. Overall, the study provides valuable insights into the potential of electromagnetic drive valve mechanisms for improving FPEG efficiency and reducing energy consumption.

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P04

Study of Mechanical Properties of Porous Titanium Alloy Spinal Cage Fabricated Via 3D Printing

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ABSTRACT

Interbody fusion devices are gaining acceptance as a treatment method for disc degeneration diseases and other medical conditions. The posterior lumbar interbody fusion (PLIF) cage maintains stability and promotes fusion between vertebrae. However, subsidence usually happens clinically due to changes in Elastic Modulus between the spinal cage and the vertebrae bone. A porous structure might reduce the elastic Modulus of the lumbar cage. This study aimed to develop and evaluate the porous of the PLIF cage made of titanium alloy with inhomogeneous Lumbar spinal bone L4 and L5 to close mechanical characteristics with bone and avoid stress shielding for bone tissue engineering applications. The finite element method was used to analyse eight various porosities of the spinal cage installation between vertebral bone L4 and L5. The stress behaviour of a PLIF cage composed of Titanium alloy was analysed using the finite element method, and the stress distribution of L4-L5 with cage was determined. The findings indicate that the percentage of porosity substantially impacts the stress distribution for the spinal cage design. Consequently, it was confirmed that the 3D model was inhomogeneous and reliable for FEA analysis. To anticipate the biomechanical behaviour of the cages after implantation, a mathematical model will be developed utilising simulation and testing data.

Keywords: Spinal Cage, Finite Element Analysis, Interbody Fusion Implant, Subsidence, Titanium Alloy.

INTRODUCTION

Degeneration of discs between one or more vertebrae can cause discomfort on both sides of the degenerative disc that could need a spinal fusion of the vertebrae. Spinal fusion is a surgical procedure that completely connects two or more vertebrae in the spine to stop the pain and motion (Meena et al., 2022). Surgery of spinal fusion is inserting bone or a bone-like substance between two spinal vertebrae.

The lumbar spine at the lower back is a complicated structure composed of L1 through L5, L4 and L5 and is the lowest vertebrae in the spine and the joints, discs, nerves and tissue are intact (Knezevic et al., 2021). This structure offers an array of functions which is the critical element of the L4 and L5, which allows the motion in all directions and also a movement from the upper part of the body.

Posterior Lumbar Interbody Fusion (PLIF) reaches the spine in the lower back by inserting a cage made of allograft bone or synthetic material (PEEK or titanium) directly into the intervertebral disc. The posterior lumbar intervertebral disc (PLIF) has been shown to be effective in treating movement-induced discogenic pain and was once considered the standard treatment for degenerative disc disease (Yu et al., 2008). Effective PLIF can restore disc height, decompress dural sacs and nerve roots, stabilize intervertebral discs and ensure anterior structures bear the load (Krijnen et al., 2006).

Computed Tomography (CT) has become the primary interbody fusion evaluation technique. The CT is quick, gives a high-quality reformatted image potential in the coronal and sagittal planes and excellent bone detail (Berger-Groch et al., 2020).

The innovative and modern method of Additive Manufacturing (AM) offers a tremendous possibility of fully controlling mechanical features such as the pores that substantially impact the characteristics of cages. In particular, 3D-printed Titanium-alloy is unique and complicated structures since designed this approach has become extremely important (Shi et al., 2019).

RESULTS AND DISCUSSION

L4 and L5 lumbar were needed to test the meshing of the CAD data before assembly with the cage. This file has been divided into two parts to make this simulation as natural as possible in getting better and more accurate results. This meshing step needs to be done to ensure that this geometry does not have any problems when proceeding to the following process

The results of each specimen, having a different number of holes and slots, cause the porosity in the cage to be different. These results show that the highest percentage of porosity is specimen 5, which is 34.90%. In contrast, the lowest porosity is specimen 0, which is 21.49%. The effect of porosity in the different cages has caused different stress and displacement effects for each cage. Therefore, this study was able to be carried out well when this cage was combined with lumbar L4 and L5 to perform FEA.

The assembly process between lumbar L4 and L5 with the cage is the last process to perform FEA. As a result, two tables were generated to represent the respective solutions. **Table 4.1** depicts the von misses stress obtained after completing all FEA cages. The maximum stress has increased up to specimen 3, with the surprise the value decreased until the value of specimen 5 started to tremendously rise again.

Table 4.1: FEA Von Misses Stress of the Lumbar L4 and L5 with Cages

No. of Specimen	Minimum (MPa)	Maximum (MPa)	Average (MPa)
0	4.0527e-010	1584.2	11.79
1	4.2155e-009	1617.2	12.578
2	1.8291e-009	2329.9	10.988
3	1.6289e-009	2040.8	9.8855
4	1.6233e-009	1609.2	8.6117
5	2.9306e-009	2110.1	8.3793
6	1.7917e-009	2329.8	11.622
7	2.3195e-009	1540.8	11.748

Meanwhile, **Table 4.2** shows the total deformation received from all FEA lumbar L4 and L5 with cages. The maximum stress is decreasing until specimen 6, where it starts to increase again (see **Figure 4.1**).

Table 4.2: FEA Total Deformation of the Lumbar L4 and L5 with Cages

No. of Specimen	Minimum (MPa)	Maximum (MPa)	Average (MPa)
0	4.0527e-010	1584.2	11.79
1	4.2155e-009	1617.2	12.578
2	1.8291e-009	2329.9	10.988
3	1.6289e-009	2040.8	9.8855
4	1.6233e-009	1609.2	8.6117
5	2.9306e-009	2110.1	8.3793
6	1.7917e-009	2329.8	11.622
7	2.3195e-009	1540.8	11.748

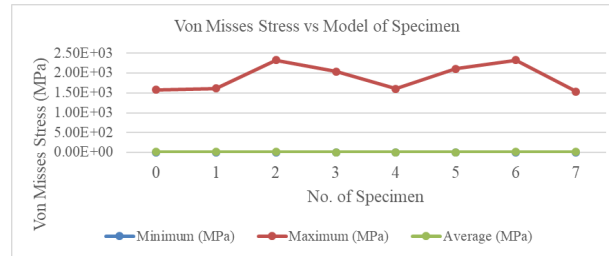


Figure 4.1: Graph Von Misses Stress of the Lumbar L4 and L5 with Cages

Figure 4.1 illustrates that the highest maximum stress is specimen 2, which is 2329.9 MPa. In contrast, the lowest maximum stress is specimen 7, which is 1540.8 MPa.

Figure 4.2 demonstrates a graph of the amount of deformation affected by the applied load and causes different changes for each specimen. The highest maximum stress is specimen 0, which is 0.095722 mm. On the other hand, the lowest maximum stress is specimen 5, which is 0.019552 mm.

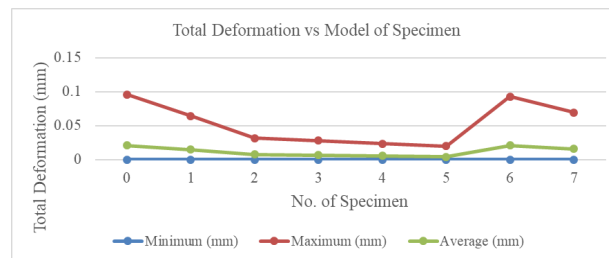


Figure 4.2: Graph Total Deformation of the Lumbar L4 and L5 with Cages

CONCLUSION

In conclusion, a total of eight (8) specimens were designed which includes the controlled specimen as well, were analysed via FEA. The purpose of the analysis was to simulate the loading conditions acting on the spinal cage structures. The results obtained from the FEA analysis demonstrate that the first research objective was successfully achieved and the values for all eight (8) specimens have been detailed out on different tests. The inconsistent FEA graph results, from von misses stress lumbar L4 and L5 with the cage, occurred because the difference in the position of the holes and slots for each cage design had an effect. The FEA graph results for total deformation of the lumbar L4 and L5 with cages is consistent by following holes, until specimen 5, and slots, until specimen 7.

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Impact of Varying the Length of The Acoustic Resonator on The Standing Waves in The Acoustic Energy Harvesting

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ABSTRACT

Noise surrounds us in bustling cities; precisely converting and collecting these undesired noises solves the sound pollution problem and opens the possibility of providing renewable power sources for low-power gadgets. A straight tube quarter-wavelength resonator with a piezoelectric patch on a flexible backplate is required to increase energy harvesting efficiency, especially in the low-frequency region. This study looks at how changing the length of an acoustic resonator affects the development and amplitude of standing waves within it. A finite element model was used to simulate standing wave formation inside resonators of different lengths and evaluate standing waves inside acoustic resonators of 100 cm, 90 cm, 80 cm, 70 cm and 60 cm. Results demonstrated that optimal standing wave amplitude can shift when the length of resonators changes. This indicates that tuning the resonator length can maximise acoustic energy harvesting performance. The models and principles explored can guide future resonator optimisation for acoustic energy harvesting applications, targeting different ambient noise profiles.

Keywords: Acoustic Energy Harvesting, Acoustic Resonator, Standing Waves, Quarter Wavelength Resonator

INTRODUCTION

The metropolitan environment is filled with heavy traffic, chatting people, construction clamour, and other noises that make up the urban soundscape (Qi et al. 2022; Rey Gozalo et al. 2019). Ambient acoustic noise in metropolitan contexts is a constant and pervasive energy source that may be used to power small electrical devices via acoustic energy harvesting (“Urban Noise - an overview | ScienceDirect Topics” n.d.; Yang et al. 2020). Acoustic resonators and their standing pressure waves are critical components of the energy transduction process, which turns acoustic noise into electrical energy (Boelkes & Hoffmann 2011; Maria Eva Amorim et al. 2011). However, the link between resonator length and internal standing wave production, crucial for energy harvesting optimisation, has yet to receive much attention in noisy urban environments (Li et al. 2013; M.P. Kazmierkowski & A.J. Moradewicz 2012; Rashad Iqbal & Mazin Abdull Majeed 2013).

This study looks at how changing the length of an acoustic resonator affects the resonant frequencies generated and the standing wave mode amplitudes developed inside it when exposed to genuine urban acoustic noise. The finite element models were developed to assess commercially feasible resonator lengths ranging from 100 to 60 cm against ambient noise exposures at 80 dB (1 Pa of total acoustic pressure). Optimising the resonator design is critical because the overall displacements induced by the stacked standing waves drive the strain and piezoelectric effect, allowing ambient acoustic oscillations to be captured. Greater standing wave displacements will result in more effective energy harvesting. This study aims to find the ideal resonator dimensions for optimising standing wave production and investigate models and concepts that might guide acoustic harvesting optimisation in noisy metropolitan locations.

RESULTS AND DISCUSSION

The plane wave source propagates the occurrence on the QWR. **Figure 5.1** displays FEA data for the frequency response of the acoustic pressure in PML and inside the QWR. A wave is propagated through the resonator and reflected on the backplate. A standing wave was created in the resonator, showing the existence of interference between sound waves travelling in opposite directions.

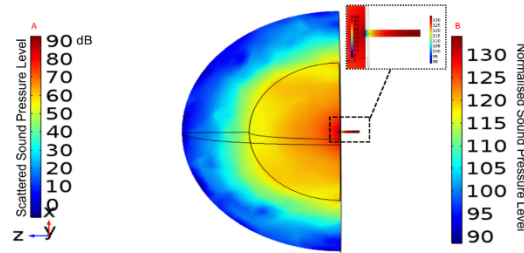


Figure 5.1: Finite element analysis of acoustic propagation inside the resonator tube.

Figure 5.2 shows the results from the FEA, which had two peaks at 71.5 Hz and 204.5 Hz for a 100 cm resonator length. The first was primarily an acoustic resonance of the QWR, whereas the second was a structural resonance of the backplate. The modes were both auditory and structural. When the length changes, both peaks shift and change based on the frequency shift and amplitude.

Table 5.1 displays the results from **Figure 5.2** for both acoustic and structural modes. It shows that the standing wave frequency shifts and increases when the resonator length decreases from 100 to 50 cm. The backplate resonance frequency also shifts when the resonator length changes, but still in the region backplate natural frequency. The amplitude of the standing waves reduces as the resonator changes.

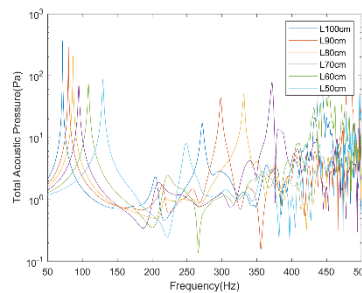


Figure 5.2: Frequency response of standing wave when the resonator length changes.

Table 5.1: Summary of the frequency response when the resonator length changes.

<i>Resonator Length [cm]</i>	<i>Standing wave frequency [Hz]</i>	<i>Amplitude (Acoustic pressure) [Pa]</i>	<i>Resonance frequency [Hz]</i>	<i>Amplitude (Acoustic pressure) [Pa]</i>
100	71.5	369	204.5	2.4
90	80	290	214.5	1.7
80	86.5	210	219	1.06
70	94.75	70.3	220	1.89
60	108.75	74.1	222.25	2.47
50	129.75	87	225	3.15

The study looked at how modifying the resonator affected the amplitude of the generated standing waves. It was discovered that when the acoustic resonator's qualities changed, frequency shifted, and the amplitude of the standing waves inside the resonator reduced.

CONCLUSION

This study demonstrated that the length of the acoustic resonator has a significant low-frequency formation and amplitudes of standing wave modes inside it. There is an optimal resonator length that maximises the cumulative standing wave displacement amplitude, which drives the efficiency of acoustic energy harvesting through the electromechanical transduction mechanism. The finite element analysis modelling can be a powerful tool for simulating and understanding the complex interactions between acoustic resonator design and internal standing wave formation. The models were able to accurately predict the shifting of resonant frequencies and related changes in standing wave amplitude across the tested resonator lengths between 50 and 100 cm.

It also confirmed that the finite element approaches are suitable for mapping the acoustic resonance properties of various-shaped resonators under real-world ambient noise situations. The enhanced standing wave increases the strain induced in the piezoelectric harvesting material, enabling higher electrical power output.

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Enhanced Leak Diagnosis in Water Pipelines: Comparative Analysis of EEMD-HT and EMD-HT Methods.

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ABSTRACT

Non-revenue water (NRW) poses a critical challenge to water utilities worldwide, affecting sustainability and causing revenue losses due to apparent and actual failures. Various methodologies, such as data-driven and model-driven approaches, have been proposed for leak detection, emphasising precise localisation's significance in minimising water loss. Transient-based methods, particularly the Transient Reflection Method (TRM), have gained attention for their efficiency in detecting and localising leaks in pipeline systems. However, TRM's accuracy in viscoelastic pipelines and leak sizing approximation has prompted further investigation. This study applies Empirical Mode Decomposition with Hilbert Transform (EMD-HT) and Ensemble Empirical Mode Decomposition with Hilbert Transform (EEMD-HT) for time-frequency analysis of transient pressure waves in pipeline systems. The objective is to compare the percentage error between EMD-HT and EEMD-HT in accurately detecting and pinpointing leak locations across diverse datasets. Preliminary laboratory tests validate the methodology's application, analysing pipe features like leakage, elbows, and junctions and discussing the test results for pipeline maintenance and water loss mitigation.

Keywords: Non-revenue water, Leak detection, Transient reflection method, Empirical Mode Decomposition, Ensemble Empirical Mode Decomposition

INTRODUCTION

Non-revenue water (NRW) refers to the difference between the supplied and billed quantity of water due to apparent and actual losses. It is a significant issue that affects the sustainability of water resources and can lead to revenue loss for water administrations (Wan Mohammad, 2023). Various strategies have been proposed to reduce NRW, including leak detection and localisation.

Leak detection and localisation methods prevent water loss in water distribution systems. These methods involve using data gathered from sensors installed throughout the system to detect and locate leaks (Min et al., 2022). Various approaches have been proposed, including data-driven methods that utilise pressure data to identify pressure losses caused by leaks (Ma et al., 2022). These methods rely on well-calibrated hydraulic models and water demand patterns to differentiate between legitimate water demand and additional flows due to leak (Shabangu et al., 2022). Additionally, model-driven approaches that combine hydraulic modelling and machine learning-based classification have been developed to localise leaks accurately (Mazaev et al., 2022). Therefore, these methods aim to rapidly and accurately detect and locate leaks, enabling water utilities to minimise water loss and optimise the operation of water supply systems.

Transient-based methods for leak detection in water pipelines have received significant attention in recent years. These methods involve analysing the pipeline system's energy transfer and dynamic response. One approach is the use of Machine Learning (ML) techniques, such as inverse transient analysis (ITA), transient reflection method (TRM), system response method (SRM), and transient damping method (TDM) (Xu & Karney, 2017).

Since there are various methods to analyse transient-based methods, this research focuses on applying the instantaneous frequency analysis method for transient reflection in water distribution networks. TRM provides an efficient and non-invasive means of detecting and localising leaks or anomalies within pipelines, facilitating proactive maintenance and ensuring the integrity and reliability of pipeline systems. These methods rely on the measurement of reflected waves caused by leaks. TRM has shown good accuracy for detecting leaks in elastic pipelines, but their accuracy is relatively low for viscoelastic pipelines (Zhang et al., 2023).

This study employs the Empirical Mode Decomposition (EMD), Ensemble Empirical Mode Decomposition (EEMD), and Hilbert transforms (HT) algorithms for the time-frequency analysis of transient pressure waves. These algorithms are more suitable and efficient for analysing nonlinear and non-stationary signals compared to traditional methods such as wavelet and Fourier analysis (Huang et al., 1998). The objective is to investigate the percentage error between Empirical Mode Decomposition with Hilbert Transform (EMD-HT) and Ensemble Empirical Mode Decomposition with Hilbert Transform (EEMD-HT) by analysing how close their estimations are to the actual leak.

RESULTS AND DISCUSSION

The experimental data collected from the transducers using MATLAB provides insight into the behaviour and characteristics of the pipeline system. The transient pressure waves propagate along the pipeline system in both directions, away from the burst's origin, at the speed of sound within the water distribution system.

The raw signal is subject to several forms of noise, including pump noise, pipe vibration noise, ambient noise, and other sources of interference. The genuine signal is obscured within a signal that encompasses extraneous noise. Therefore, signal processing is employed in this study to eliminate any outside signals detected by the pressure sensor.

Figure 6.1 illustrates the signal response of the leak (1 mm) data captured during a laboratory experiment with a pressure of 1 bar inside the pipeline. The initial peak amplitude in the signal response, as depicted in **Figure 6.1**, corresponds to the opening and closing of the solenoid valve. This action generates pressure transients that propagate and reflect throughout the pipe system.

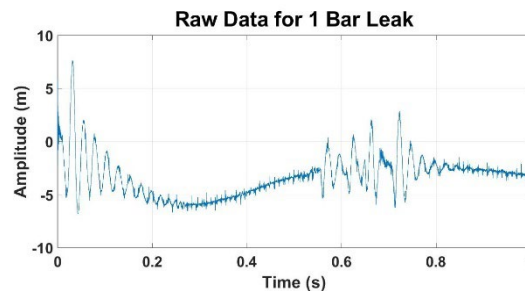


Figure 6.1: Original signal response for 1 bar Leak (diameter :1 mm)

Figures 6.2 and **6.3** display the estimation of instantaneous frequency (IMF) for leaks following the application of the HT process.

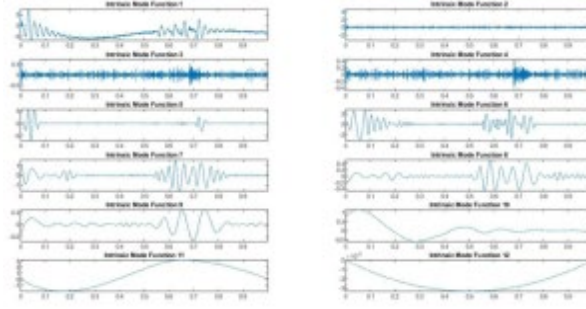


Figure 6.2: IMF level 1-12 after EMD process for 1 bar Leak (diameter :1 mm)

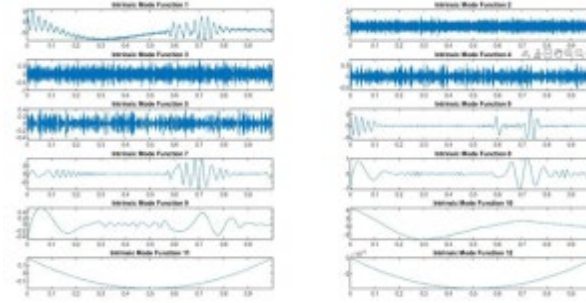


Figure 6.3: IMF level 1-12 after EEMD process for 1 bar Leak (diameter :1 mm)

These figures depict the relationship of amplitude versus time for the first 12 levels of IMF. The first level of IMF comprises higher frequency signals, considered as noise signals. Conversely, the last group is reserved for lower-frequency signals. The first and second levels of IMF are excluded from further analysis due to the presence of noise frequency signals. However, IMF level 7 and the residue component contain essential network responses. Consequently, these IMF components are discarded. The remaining IMF levels, specifically IMF level 3 to IMF level 6, are combined to generate a noise-free signal (Yusop et al., 2021).

Equation 1 shows the distance between the reflection point and the point of analysis is calculated using the below formula (Taghvaei et al., 2006),

$$\text{Distance, } s = \frac{\text{Time, } t \times \text{speed of sound, } c}{2} \quad (1)$$

where the speed of sound in the pipeline system ($c = 479$ m/s) is divided by two, owing to back-and-forth wave travel.

Figures 6.4 and 6.5 show the estimation of instantaneous frequency for leak (1 mm) data. In this phase, the nonstationary nature of the signal, where the frequency value changes dynamically over time, is considered. Instantaneous frequency refers to the frequency that accurately represents the local behaviour of the signal (PiRemli et al., 2021).

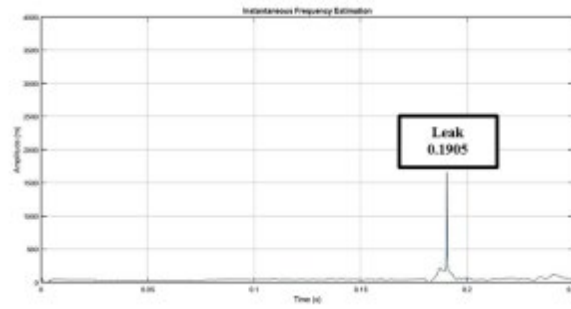


Figure 6.4: Instantaneous Frequency Estimation versus time (s) graph for 1 bar Leak (1 mm) – EMD-HT

Figure 6.4 displays the outcomes of the frequency analysis conducted using the HT for a leak size of 1 mm, with the spike occurring at a time of 0.1905 s (distance: 45.62 m). The outcome depicted in Figure 6.4 exhibits a distinct peak in reflection, albeit with a slight deviation from the precise value of 45.62 m. The occurrence of a spike within the range of 0 to 15 m can be attributed to various sources, including the generation of transient waves, water hammer resulting from the solenoid, and signal contamination caused by noise.

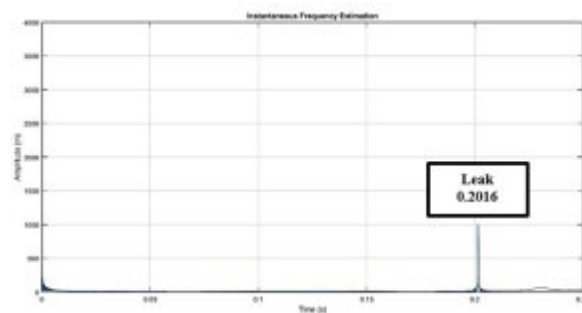


Figure 6.5: Instantaneous Frequency Estimation versus time (s) graph for 1 bar Leak (1 mm) – EEMD-HT

Figure 6.5 shows the spike that occurs at 0.2016 s, with a corresponding distance of 48.28 m. The observed outcome demonstrates a discernible presence of signal noise compared to the subsequent analysis phase employing the EMD-HT technique. This phenomenon occurs due to applying the EMD approach, which involves the introduction of additional white noise into the original signal. The noise in the analysis process may occasionally result in the desired peak being masked. Nevertheless, the magnitude of the instantaneous spike of the leak still appears to be more extensive when compared to the others.

Table 6.1 shows the summary of the combined analytical results of this study's EMD-HT and EEMD-HT methods. The side-by-side comparison of the results demonstrates and justifies the significant improvement of the EEMD-HT method regarding leak diagnosis and localisation error. Furthermore, the EEMD-HT technique demonstrated high stability in accurately locating the location of leaks across all 50 datasets. Based on comprehensive data sets, the EEMD-HT technique demonstrates the capability to effectively identify and pinpoint the presence of features and leaks inside the constructed pipeline system.

Table 6.1: Comparison between EMD-HT and EEMD-HT Method in term of Percentage Error

Water pressure	Pipe Features	Percentage Error (%)	
		EMD-HT	EEMD-HT
1-bar	T-junction	7.48	4.07
	Elbow	7.83	1.07
	Leak	6.77	1.34
2-bar	T-junction	7.58	4.27
	Elbow	6.33	1.51
	Leak	6.04	3.10

CONCLUSION

Different pipe faults commonly utilised for inquiry encompass leakages and other types of connections, such as T-junction and Elbow. The application findings provide evidence supporting the validity and accuracy of the suggested time-frequency analysis method in identifying various types of pipe defects and their respective locations. Additionally, the locations of these faults were detected with a relative error of no more than 5% for the test system using the EEMD-HT method. In the present study, the proposed methodology effectively isolates and mitigates extraneous signals in the initial recorded transient pressure wave data.

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The Effect of Grain Refinement on Microstructure Formation of Al-Si Alloy via Semisolid Processing

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ABSTRACT

The semisolid metal processing (SSMP) is a promising technique in casting industries that may overcome the imperfection of the component that produced by the conventional casting process. The SSMP process involve the production of globular microstructure rather that dendritic structure produced from traditional casting process. Grain refinement is an essential technology in SSMP that enables precise control of the microstructure and improved mechanical properties of cast metals. In this experimental work, the Al-Si alloy was processed using direct thermal method to produce SSMP feedstock billets. The alloy was treated with different processing parameters that consists of pouring temperature, holding time and magnesium addition. The result shows that sample 3, with processing parameter of 590 °C, 15 s and 1.5 wt%, produced the smallest grain size at 802.037 μm^2 . It was discovered that the circularity and ferret diameter were found to be 0.77 and 41.50 μm , respectively. Clearly, the microstructure of sample 3 was more refined and globular in structure. According to the findings from the literature, the higher magnesium content clearly refined the α -Al grain structure and produced more globular grain particles.

Keywords: Semisolid Processing, Grain Refinement, Aluminium Silicon Alloy, Direct Thermal Method, Globular Microstructure.

INTRODUCTION

Casting is a time-honoured and demanding technique in the manufacturing process, which involves the process of pouring the molten alloy into the mould and allowing it to solidify (Salonitis et al., 2016, Lehmhus, 2022). Metal casting is an essential procedure in the manufacturing sector that yields a wide range of components on a large scale. The primary issue faced by modern casting industries is the acquisition of materials with excellent quality in terms of microstructure analysis, mechanical characteristics, and stress-strain behaviour. The quality of the material is crucial in attaining the desired level of excellence for manufacturing industry. Improper material quality component will inevitably lead to structural failure, which might cause serious injury. Nevertheless, the enhanced mechanical characteristics of metal typically need the use of heavy metals, which can hinder mobility and flexibility, resulting in challenges to manufacture such components.

The aluminium alloy is frequently utilised to produce materials with enhanced strength and other desired characteristics. Aluminium alloy plays significant importance in metal casting, particularly in the aerospace and automotive sectors. The mechanical properties of materials are crucial in ensuring optimal quality in the manufacturing business. As example, the automobile sector utilises aluminium

alloy to manufacture vehicle parts, including engine blocks, in order to reduce weight compared to cast iron, which is heavier than aluminium (Miller et al., 2000). The automotive components are typically manufactured by conventional metal casting process. The application of conventional casting processes results in the production of shrinkage porosity in the components or materials, which in turn decreases their mechanical properties and increases the possibility of rejection. However, the utilisation of semisolid metal processing (SSMP) has the potential to overcome this frequently encountered issue in traditional casting.

The development of SSMP by Flemings and his colleague at the Massachusetts Institute Technology (MIT) in the 1970s was undoubtedly one of the most momentous and consequential occurrences of that decade (Chang et al., 2020, Jiang et al., 2020). The SSMP enables the formation of globular microstructure rather than dendrite structure produces by conventional casting process. **Figure 7.1** shows the comparison between dendritic structure formation and near globular semisolid structure formation. The fluidity of the molten alloy changes significantly between the solidus and liquidus temperature. The microstructure behaviours of the SSM processing were characterised by liquid-like flow behaviour when the shear was applied, and solid-like behaviour was observed under rest conditions. The SSMP can be classified into two common methods consisting of rheo- and thixo- route. The rheocasting technique involves the direct processing of raw material without an intermediate solidification stage. The technique utilises shearing forces during the solidification process to produce a semisolid slurry with a globular microstructure. This slurry is subsequently put into a mould and cast of various components.

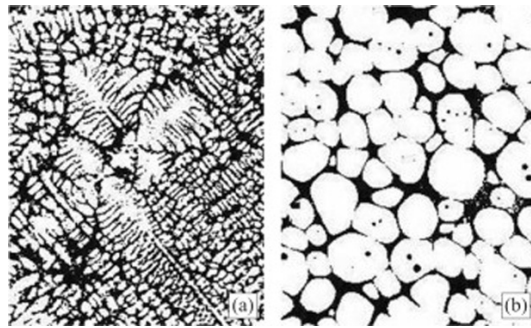


Figure 7.1: Comparison of (a) dendritic structure by the conventional casting process and (b) near-globular semisolid microstructure of aluminium A357.

Grain refinement is an essential technology in SSMP that enables precise control of the microstructure and improves mechanical properties of cast metals (Guan & Tie, 2017; Lloyd, 1994). It reduces the average size of the grains in the solidified metal, resulting in a refined and more homogeneous grain structure. The mechanical properties are influenced by the diameter of the particle size, with smaller particle sizes improving tensile strength and greatly increasing ductility. It has also been suggested to use larger particles with higher grain size to improve the material's ability to deform at high temperatures. Casting components with a refined grain structure are less vulnerable to faults, such as hot ripping, and isolate high porosity during the solidification process; it also reduces pressure tightness. The grain refinement technique can be divided into four main groups which consist of severe plastic deformation (SPD), rapid solidification (RS), grain refinement by mechanical vibration and the addition of grain refiner.

Various techniques have been explored in order to produce refined and globular grain structure SSMP feedstock billets. Among those techniques, the grain refinement method has emerged as a prominent technique to produce more globular and smaller particles size during SSMP (Kashyap & Chandrashekar, 2001; Zaid, 2016). The addition of titanium, particularly when combined with carbon or boron, has been found to have a beneficial refining impact in aluminium. Since then, the method of adding inoculant has become an industrial practice to refine the grain structure formation of the alloy. The application of grain refinement has been shown to improve the morphological properties of the

microstructures of the starting material, leading to a remarkable shift towards more globular and finer grain size. This advancement is a crucial turning point in utilising the complete capabilities of SSMP and provides the basis for developing high-performance materials with exceptional attributes. While the dendritic structure transformation of the alloy to a globular form through SSMP has been established, the impact of incorporating inoculants into the alloy via the Direct Thermal Method (DTM) remains uncertain, primarily attributed to the limited literature available in this specific research domain. Hence, this paper aims to study the effect of inoculant addition (magnesium) to the microstructure of Al-Si alloy semisolid feedstock billet produces by DTM.

RESULTS AND DISCUSSION

The processing parameters for the manufacturing of SSM feedstock billets comprises three factors: pouring temperature, holding time, and magnesium addition (wt%). **Table 7.1** represents the processing parameters used to produce SSM feedstock billets by direct thermal method.

Table 7.1: Processing parameters used to produce SSM feedstock billets by DTM process.

Sample	Temperature (°C)	Holding time (s)	Magnesium Addition (wt%)
1	590	15	0.5
2	590	10	1
3	590	15	1.5
4	590	20	1

The microstructure formation was examined using an optical microscope and the detailed analysis was carried out using Image J software. The grain size, circularity and Ferret diameter were analysed.

$$Circularity = 4\pi A \quad (1)$$

Figure 7.2 represents the microstructure formation for each sample (1–4). Meanwhile, **Figure 7.3** (a), (b) and (c) represents the average grain size, circular and diameter of each sample. Sample 3, with pouring temperature of 590 °C, holding time of 15 s and 1.5 wt% magnesium addition, produced the smallest grain size particles at 802.037 μm^2 . Sample 3 also has the most globular grain structure as compared with others sample with circularity of 0.77. The circularity value that is near to 1 is the most globular and spherical shape. Sample 3 also has the lowest ferret diameter value, which was at 41.50 μm . Further analysis shows that sample 4, with processing parameter of 590 °C, 20 s and 1 wt% magnesium, has the largest grain structure at 1201.58. Its circularity and ferret diameter for were 0.62 and 54.02, respectively.

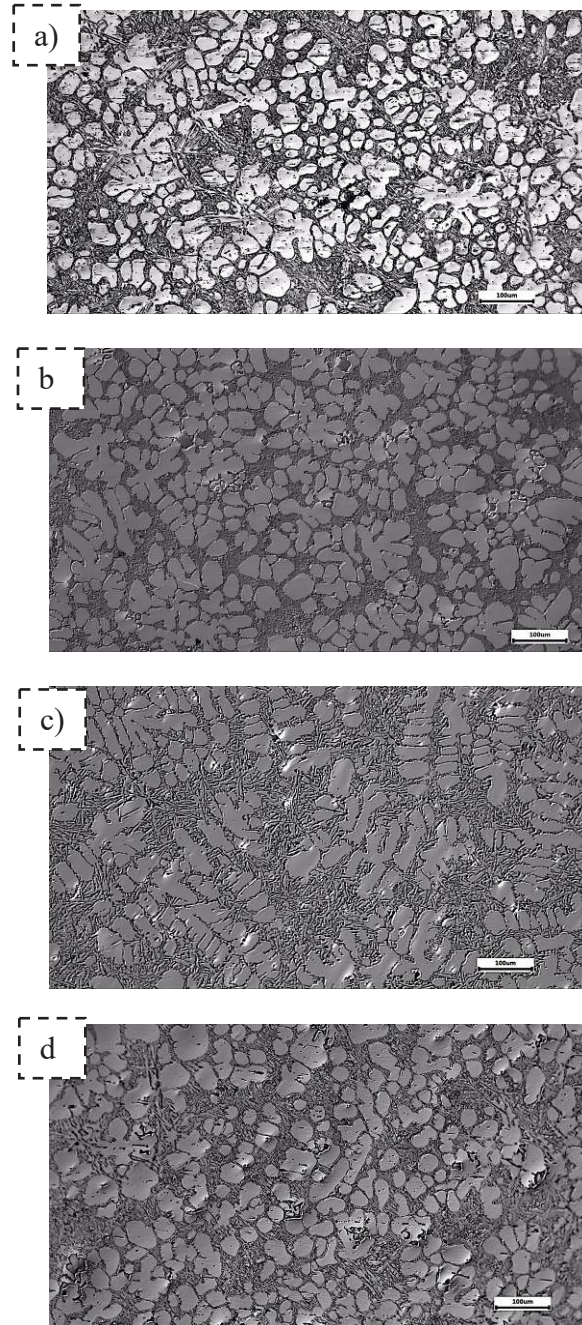
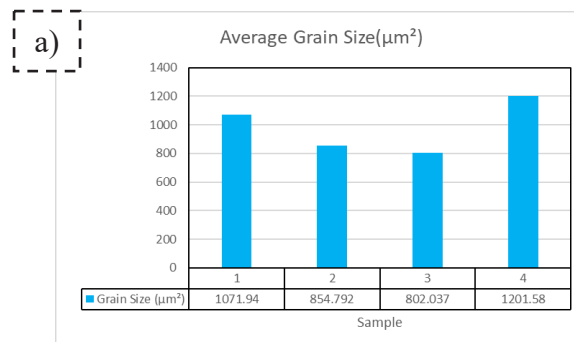


Figure 7.2: Microstructure for (a) sample 1, (b) sample 2, (c) sample 3 and (d) sample 4.



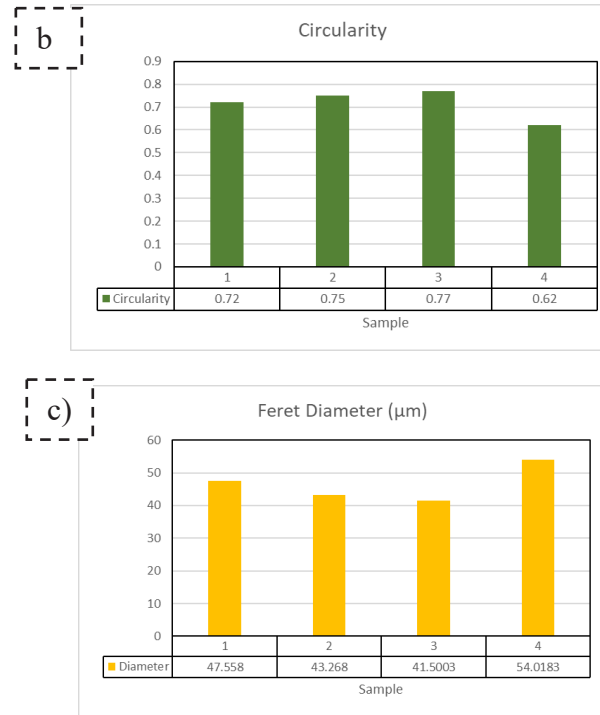


Figure 7.3: Microstructure analysis consists of (a) average grain size, (b) circularity and (c) feret diameter.

The microstructure image of the Al-Si alloy clearly shows that the addition of magnesium modifies the primary phase of the α -Al from dendritic to near globular and rosette structure. The alteration in the morphology of the silicon phase in hypoeutectic Al-Si alloy is associated with a reduction in the eutectic temperature and an increase in undercooling, suggesting that elevated concentrations of Mg have a substantial impact on the silicon phase of hypoeutectic Al-Si alloy. The presence of these modifications suggests that the production of Mg_2Si has taken place (Kori et al., 2009). Furthermore, the holding time was primarily intended to ensure that enough solid fraction was achieved before the quenching process. The solid fraction within the molten alloy influenced the globular microstructure formation during the solidification process. The larger grain size of alloy microstructure is caused by the longer holding time used before the solidification process. The formation of globular microstructure and smaller grain size was determined by the volume of fraction solid in molten aluminium alloy before it was quenched into a water tank (Anson & Gruzleski, 1999; Avelle et al., 2002; Haga & Kapranos, 2002; Reisi & Niroumand, 2012). The longer holding time promoted the development of the grain within the alloy and produced a larger grain. On the other hand, the increasing of Mg concentration within the melt affect the microstructure formation during solidification process. These results are correlated with the previous findings that the increasing of Mg content produced finer globular α -Al phase and eutectic silicon (Alhawari et al., 2016).

CONCLUSION

The experimental works investigated the effect of different processing parameters on the formation of the microstructure Al-Si alloy feedstock billets produced by DTM. Sample 3, with pouring temperature of 590 °C, holding time of 15 s and 1.5 wt% magnesium addition, produced the smallest grain size particles at 802.037 μm^2 . The largest grain size was 1201.58 μm^2 , with the processing parameter of 590 °C, 20 s and 1 wt% magnesium. The addition of magnesium resulted in a change in the morphology phase of the primary α -Al phase from the dendritic morphology to the nearly globular and rosette-like α -Al grains. It was discovered that the addition of Mg resulted in a reduction in the particle size of the sample.

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P08

Titanium-Based Nano Additives in Heat Transfer Fluid: A Review

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ABSTRACT

This study explores the transformative impact of titanium-based nano additives on heat transfer fluids, drawing insights from an extensive review of 24 articles on Scopus and WoS databases. There are three main themes that represent the current study trends of nanofluid, which are: (1) magnetic and thermal effects on nanostructures in fluid flow, (2) solar thermal installations and photovoltaic panel efficiency, and (3) nanofluid heat transfer enhancement. The synthesised findings reveal a nuanced understanding of titanium-based nano additives' role in elevating thermal conductivity and stability of fluids. This research contributes to the evolving discourse on nanotechnology applications, providing a foundation for optimising heat transfer fluid formulations for enhanced industrial performance.

Keywords: Heat Transfer, Nano Additives, Titanium, Properties, Nanofluid

INTRODUCTION

In the ever-evolving landscape of thermal management, the incorporation of nanotechnology has emerged as a transformative avenue, reshaping the performance and efficiency of heat transfer (Colangelo *et al.*, 2023). As we delve into the intricacies of this dynamic field, our systematic review aims to comprehensively explore the recent advancements and pivotal findings surrounding the integration of nano additives in heat transfer fluids (Bhattad *et al.*, 2023). Heat transfer fluids, commonly utilised in various industrial and technological applications, play a crucial role in dissipating heat and maintaining optimal operating temperatures (Rahmadiawan *et al.*, 2021). The traditional fluid formulations, though effective, are now undergoing a paradigm shift with the infusion of nanomaterials. Nanoparticles, with their unique physical and chemical properties, offer a novel approach in augmenting the thermal conductivity, stability, and overall efficacy of these fluids (Shahzad *et al.*, 2022).

This systematic review critically assesses a spectrum of nanomaterial with Titanium-based element (Ali *et al.*, 2018). The comprehensive analysis extends beyond the synthesis methodologies, encapsulating the impact of these nano-additives on critical parameters such as viscosity, heat capacity, and thermal stability (Liu *et al.*, 2022). As we traverse through the literature, a particular emphasis is placed on elucidating the underlying mechanisms and interactions governing the enhanced heat transfer properties facilitated by nanomaterials. The nano-scale effects on fluid flow, convective heat transfer, and nucleation phenomena are scrutinised to unravel the intricacies that dictate the observed improvements in thermal performance (Hossain *et al.*, 2022).

RESULTS AND DISCUSSION

This impactful article encompasses diverse studies in nanofluid dynamics and heat transfer enhancement. The first investigation explores nanostructure motion in magnetohydrodynamic (MHD)-affected flow towards heated porous sheets, considering MHD effects and partial slip (Naseem *et al.*, 2023). The second study investigates the influence of a magnetic field on unsteady MHD water-based nanofluid flow across an infinite flat plate, incorporating radiative heat transfer in a porous material (Reddy & Shankar Goud, 2023). Results reveal the effects of radiation and magnetic parameters on velocity and temperature profiles.

The third research explores localised magnetised force on nanostructures in a trihybrid nanofluid flow, revealing intricate vortex structures and significant increases in skin friction and Nusselt number with a strengthened magnetic field (Ahmad *et al.*, 2023). Lastly, a study on MXene and functionalised graphene hybrid nanofluids for micro-scale cooling introduces a novel application for electronic device thermal management (Arifutzzaman, Saidur & Aslfattahi, 2023). **Figure 8.1** is the overview of the study.

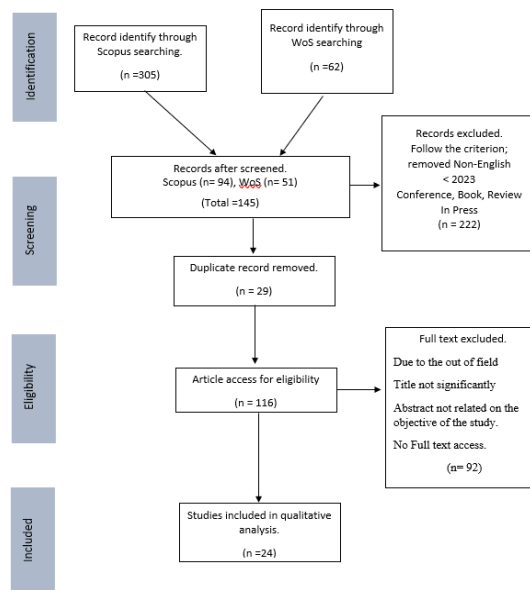


Figure 8.1: Flow diagram of the proposed searching study.

CONCLUSION

In summary, the studies explored the incorporation of Titanium-based nanoparticles into various materials to improve their thermal properties for a wide range of application. The experiments focused on enhancing heat transfer, thermal conductivity, and thermal resistance of materials by including a combination of nano-additives. The results exhibited substantial improvements in the thermal characteristics of the materials, making them appropriate for use in solar water desalination devices, heat storage systems, and heat transfer fluids.

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P09

A Review of Autonomous Vehicle Sensors and Fusion Technologies

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ABSTRACT

The significant advancements in sensors and communication technology, coupled with the application of object detection technology and algorithms, are transforming autonomous driving into a game-changing technology for future transportation. Sensors play a pivotal role in the detection of the surrounding environment in auto drive systems, and sensor fusion technology holds the key to ensuring the safety and reliability of autonomous vehicles. This paper delves into the sensors commonly employed in autonomous vehicles, with a focus on cameras, LiDAR, millimetre wave radar, and their practical applications. It also summarises the three primary sensor fusion methods and provides an overview of the most advanced sensor fusion technologies and target detection algorithms currently available in auto drive systems.

Keywords: Sensor Fusion; Self-driving Vehicles; Camera; LiDAR; Radar

INTRODUCTION

Most autopilot systems have some drawbacks in real life. Extreme weather conditions can impact safe driving as they can severely affect the performance of sensing sensors. For instance, strong light, snow, fog, and rain can all have negative impacts. Each type of sensor has its own advantages and disadvantages. Radar, for example, can accurately determine distance and speed in adverse weather conditions, but it is unable to recognise street signs or distinguish the colour of traffic signals. Cameras are effective at recognising street signs and classifying objects, such as pedestrians, bicycles, or vehicles. However, they are susceptible to interference from dust, rain, and snow. In self-driving cars, sensors play a crucial role in sensing the surrounding environment and facilitating path planning and decision making. Currently, the most commonly used sensors are cameras, LIDAR, and millimetres-wave radar. The sensors' performance varies and can be advantageous depending on the usage environment. Sensor fusion technology integrates data from multiple sensors to accurately reflect the surrounding environment and improve system decision-making. Currently, sensor fusion is focused on automated driving perception technology.

SENSORS USED IN SELF-DRIVING

Sensors are a crucial component of an autonomous driving system, serving as detection devices. Their main function is to convert measured information into specific patterns of output information. **Figure 9.1** illustrates the composition of autonomous driving sensors, which primarily include cameras, radar sensors, LiDAR sensors, and other devices for perceiving the vehicle's surroundings. (Wang, Wu & Niu, 2020).



Figure 9.1: Common autopilot sensor components

CAMERA

The camera is the most frequently utilised sensor in autonomous vehicles, enabling the perception of objects in the surrounding environment and facilitating the identification of objects on the road. Camera usually consists of a lens, an image sensor, an image signal processor (ISP), and an input/output (I/O) interface ('Image sensor', 2023). Lens collected the reflected light from the target, and its convergence to the image sensor. Then, the image sensor converts the light wave into an electrical signal and converts the electrical signal into a digital value through an on-chip ADC. After that, the ISP performs post-processing (for example, noise reduction) and converts the digital value to the RGB data format of the image or video. Finally, the image data is transmitted and displayed through the I/O interface. Collision warning, lane deviation alarm, pedestrian detection, and traffic light detection are among the functions that can be achieved by perceiving the vehicle's surrounding environment. Autonomous vehicles typically use visible light cameras to detect road markings and construct a 360-degree view of the environment. However, visible light cameras have limited capabilities in low visibility conditions. In addition, the processing of the considerable amount of video data generated by multiple cameras necessitates substantial computing hardware.

LiDAR

LiDAR technology has continuously evolved over the past few decades and remains a core perception technology for Advanced Driver Assistance Systems (ADAS) and autonomous vehicles. When a LiDAR scans its surroundings, it generates a 3D scene in the form of a point cloud, providing a series of data, also known as point cloud data. This data estimates the distance required between the emission and reception of pulses. LiDAR is commonly used in autonomous vehicles due to its wider field of view, longer detection range, and stronger depth perception, which provide reliable and precise data. However, it cannot provide colour information of the surrounding environment, which is one of the reasons why point cloud data often utilises sensor fusion algorithms (Royo & Ballesta-Garcia, 2019). Moreover, LiDAR is the most expensive sensors.

RADAR

Millimetre wave radar, also known as Radio Detection and Ranging (RADAR), is an abbreviation for electromagnetic wave detection and ranging. Its operating principle involves radiating electromagnetic waves in a designated area, receiving scattered (or reflected) waves from the target, and providing distance information of the target for further signal processing. The Doppler characteristics of electromagnetic waves are utilised to determine the relative velocity and position of detected obstacles. The Doppler effect, also referred to as Doppler frequency shift, describes the change in frequency or offset of waves resulting from the relative motion between the wave source and the target. For example, if the target moves towards the radar system, the frequency of the received signal (shortwave) increases

(Jia, Guo and Wang, 2018). Millimetre wave radar is one of the most frequently used sensors in autonomous driving systems. They are frequently used in autonomous vehicles to ensure dependable and precise obstacle perception in all weather conditions. They are capable of detecting moving obstacles and operating within short, medium, or long ranges based on configuration modes, making them effective in adverse weather conditions. However, due to their relatively low resolution, they are generally not suitable for bidirectional recognition applications. Researchers of autonomous vehicles often integrate millimetre wave radar information with other sensing data to compensate for the limitations of millimetre wave radar sensors. This approach helps to overcome the limitations of millimetre wave radar sensors.

SENSOR FUSION TECHNIQUES AND ALGORITHMS

Sensor Fusion is an important research direction of most automotive drive systems. This method integrates data collected by multiple sensors, reducing the uncertainty of the detection data and compensating for the disadvantages of independent operation of a single sensor. In addition, sensor fusion helps to build consistent models and accurately perceive the environment under different environmental conditions. For example, camera and radar fusion can provide high-resolution images and perceive the relative speed of obstacles detected on the scene (Simonyan & Zisserman, 2015). Multiple sensors of the same or different types provide different local and categorical information, which can be complementary, but also redundant and contradictory. In the end, the control centre can only issue the single correct command, which requires it to fuse and make comprehensive judgments on the information obtained from multiple sensors.

According to the analysis, the possible misjudgement of relevant sensors has become one of the main reasons for safety accidents caused by autonomous driving. Therefore, when using multiple sensors, it is necessary to fuse the information of the sensors to ensure safety. Multi-sensor fusion can greatly improve the redundancy and fault tolerance of the system, thus ensuring the speed and accuracy of decision making, which is an inevitable trend in autonomous driving. At present, there are mainly three sensor combinations for obstacle detection, including camera-LiDAR (CL); camera-radar (CR); combined with cameras and LiDAR-radar (camera-LiDAR-radar CLR) sensors. The CR sensor combination provides high resolution imagery while providing additional distance and velocity information of surrounding obstacles. The combination of CLR sensors can provide a wider range of resolution and accurate understanding of the environment through LiDAR point clouds and depth information, improving the overall safety redundancy system of autonomous driving.

Sensor fusion technology and algorithms have been widely studied in recent years. Current technologies and algorithms can be divided into classical sensor fusion algorithms and deep learning sensor fusion algorithms. First, classical sensor fusion algorithms, such as knowledge-based methods, statistical methods and probabilistic methods, use the uncertainty theory of data incompleteness to fuse sensor data, as shown in **Figure 9.2**. On the other hand, deep learning sensor fusion algorithms involve the generation of various multi-layer networks that can process raw data and extract features to perform difficult intelligent tasks (**Figure 9.3**). Convolutional Neural Networks (CNN) and Recurrent Neural Networks (RNN) are the most widely used algorithms in perception systems (Wang *et al.*, 2021). Currently, a widely used weighted mean, YOLO algorithm, is used to fuse RGB camera and LiDAR point cloud data to improve real-time target detection performance. The latest YOLOv4, released in April 2020, uses CSPDarknet5 as the backbone feature extraction network to achieve the goal of reducing computation while maintaining good detection accuracy.

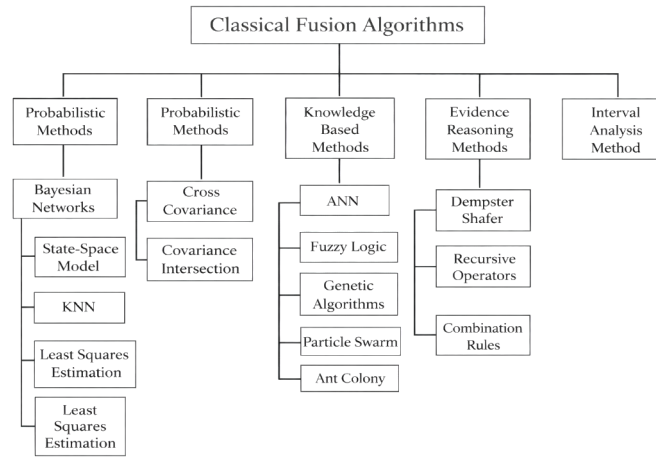


Figure 9.2: Classical sensor fusion algorithms

In addition, with the emergence of 3D sensors and various applications that understand the 3D environment around autonomous vehicles, there is also an increasing amount of research on 3D object recognition. With the gradual maturation of deep learning neural networks in computer vision, it is possible to detect and segment 3D point cloud scenes. In 2019, CCDC, a new scene segmentation method based on PointNet and VoxelNet was proposed to improve the efficiency and accuracy of semantic segmentation. First, a voxel grid method is used to sample the point cloud scene, and then the point cloud data is filtered to remove noise and smooth the surface of the point cloud. Finally, the processed point cloud scene is trained.

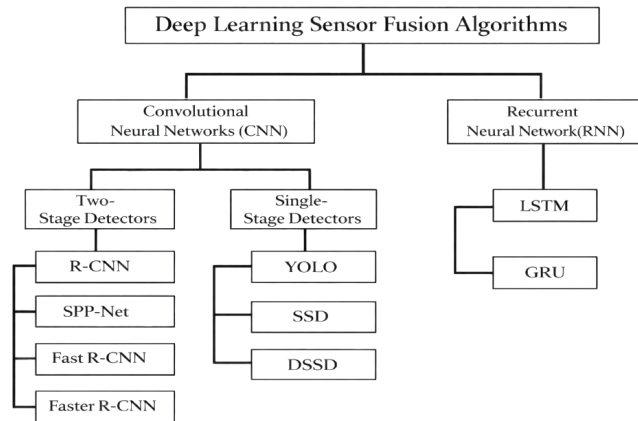


Figure 9.3: Deep learning sensor fusion algorithms

Without a doubt, after extensive research, multi-sensor fusion technology has achieved comprehensive advantages in autonomous systems such as autonomous vehicles. These systems are typically equipped with a number of sensors that can generate large amounts of data per hour. Therefore, processing this data requires significant computing power. However, training on data from all possible scenarios is challenging, so it is crucial to further research and extensively test autonomous systems by evaluating all possible solutions and the risk of possible sensor and system failures, as well as alternative solutions in case of sensor or system failure.

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

In this paper, the detection sensors in the car drive system are comprehensively investigated. Emphasis is placed on the camera, the LiDAR sensor, the millimetre-wave radar sensor, as well as their practical operation. Finally, we review some fusion algorithms that have been established in the literature and point out some challenges in the field of sensor fusion and possible future research directions of the automotive drive system. Autonomous vehicles involve a wide range of technologies, among which sensors play a fundamental role in perceiving and interpreting the surrounding environment. Since autonomous vehicles contain multiple sensors, more accurate values must be obtained through sensor fusion before algorithm processing. Accurate sensor fusion can enable autonomous vehicles to recognise their position in real coordinates. Due to external factors such as temperature and vehicle vibration, the accuracy of sensor fusion is easily affected. Therefore, improving the accuracy of sensor fusion and developing more accurate and reliable obstacle detection technologies for autonomous vehicles is the key to current and future development. It is possible to improve existing sensor fusion algorithms using reinforcement learning methods to develop more reliable and accurate obstacle detection methods.

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P10

Microencapsulation of Linseed Oil and MMT Nanoclay for Smart Self-Healing Coating

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ABSTRACT

Smart self-healing coating is a coating with self-healing ability containing active substances that can react to any stimuli in the environment when necessary. In this paper, the research on the microencapsulation of Linseed Oil (LO) as the core material, polyurea-formaldehyde (PUF) as the shell material, and MMT nanoclay via in-situ polymerisation are reported. The characterisation of the microcapsules was done by optical microscopy and FTIR analysis. Based on the FTIR spectrum, the Si-O bond detected confirms the presence of MMT nanoclay in the microcapsules. The formation of microcapsules was observed by optical microscopy. The average diameter of the microcapsules is ca. 30 μm with rough outer surfaces.

Keywords: Microencapsulation, MMT, Linseed Oil, Smart Coating.

INTRODUCTION

Smart self-healing coating was defined as a multifunctional coating containing active substances that can respond to any stimuli in the environment, capable in self-heal to protect, extending safety and lifetime of the metal materials. Trentin et al., (2022) stated that a smart coating with self-heal ability is based on a material that, if damaged, can repair or heal itself, slowing or even stopping corrosion and, in the best-case scenario, restoring completely its functionality and aesthetic aspect. Smart coatings with self-healing ability become quite popular and widely used in the coating fields as they become the standard for the improvement in shelf-life, enhancing working consistency and eco-friendly approach and reducing repairing cost of the materials (Mahajan & Gite, 2022).

Linseed oil (LO) is extracted from flaxseed (*Linum usitatissimum*) and it is a natural oil commonly used in Europe. The application of LO as a healing agent is a natural solution that can polymerise in a short amount of time, able to self-heal and provide efficient corrosion protection to the metal alloy (Tomić *et al.*, 2022), due to its drying oxidation mechanism (Ouarga *et al.*, 2022). Research had been conducted recently by Alias et al., (2021) in which they encapsulated LO as the core material and polyurea-formaldehyde (PUF) as the shell material for epoxy resin coating matrix on Mg. alloy. Based on scratch test performed, there were results evidently showing that with the addition of LO, the coating did self-heal and provide better corrosion protection even after scratching. Another research on LO as healing agent was done by Li et al., (2022), in which they synthesised new microcapsules containing LO and cobalt octoate as the core materials, and graphene oxide (GO) as the shell material for rapid self-healing performance of the polyurethane (PU) coating for corrosion protection. They did the scratch tests with a width of 8.3 μm to observe the self-heal ability of the coating. The metal substrate was clearly seen on the scratch area, exposing the metal to the corrosion attack. However, after 12 hours, the scratch area was closed and disappeared, confirming the excellent self-healing ability of the PU coating containing LO.

Montmorillonite (MMT) nanoclay, a natural raw material, is a naturally occurring 2-dimensional lamellar silicate material. It is widely available at a low price and has a good ability to shield UV rays and corrosive media and is widely used in composites to make high-performance materials (Chen *et al.*, 2022). A few research were done on the effects of MMT nanoclay on the microcapsule formation and function. X. Wang et al., (2022) prepared self-healing capsules with MMT nanoclay and epoxy resin (ER) as the core materials and ethyl cellulose (EC) as the shell material to further regulate the release rate of the core materials.

They reported that, with the addition of MMT nanoclay, the encapsulation rate increased slightly, and the rate of slow release gradually decreased. They also reported that when the concentration of MMT nanoclay increased, the viscosity of ER was improved, and the number of pores decreased. Another research on the microencapsulation of MMT nanoclay was done by Farshi Azhar and Ahmadiania, (2023), in which they synthesised microcapsules by in-situ polymerisation of urea-formaldehyde (UF) as the shell material around the core materials inclusive of epoxy resin, calcium nitrate and MMT nanoclay. Based on their results, it is evident that the recovery rate of mechanical strength with the addition of MMT nanoclay had higher quantities as compared to microcapsules without MMT nanoclay. They also reported that the presence of low loading of MMT nanoclay in the core component improved the dispersion state and the intercalation effect of MMT nanoclay that generate high density of crosslinking network in epoxy matrix, and thus improving the mechanical properties.

LO and MMT nanoclay are widely known due to their advantages in self-healing ability and corrosion protection for the application of smart self-healing coating technology. However, to the best of our knowledge, there is no research done on the microencapsulation of LO modified by MMT nanoclay. There are also mixed studies on the actual roles of MMT nanoclay in microcapsules. Thus, in this paper, the research on the microencapsulation of LO as the core material, polyurea-formaldehyde (PUF) as the shell material, and MMT nanoclay via in-situ polymerisation are reported. The FTIR analysis of MMT nanoclay material and LO microcapsules modified by MMT nanoclay are presented and the images of the microcapsules from the optical microscopy are analysed.

PREPARATION OF MICROCAPSULES

The microcapsules were prepared via in-situ polymerisation with the addition of LO as the core material, polyurea-formaldehyde (PUF) as the shell material, and MMT nanoclay. The ingredients for the microcapsules were stated in **Table 10.1**.

Table 10.1: Ingredients for the Microcapsules

Ingredients	Quantity
Urea	7.5 g
Formaldehyde (37 wt. %) (aq)	19.02 g
Hydrochloric acid (HCl) (5 wt%) (aq)	A few drops
Poly vinyl alcohol (PVA) (5 wt%)	7.5 mL
Ammonium chloride	0.75 g
Resorcinol	0.75 g
Distilled water	200 mL
Linseed oil (LO)	50 mL
MMT nanoclay	3 wt%
Ethanol	100 mL

The preparation on microcapsules began by mixing 200 mL distilled water and 7.5 mL PVA solution into a 500 mL beaker. After stirring for a few minutes at room temperature, urea, ammonium chloride (hardener) and resorcinol (cross-linker) were added. The mixture was stirred for 30 minutes until dissolved. The pH value was adjusted to the range between 3 and 4 using a few drops of HCl aqueous solution. Then, 50 mL LO, 3 wt% MMT (by distilled water mass) and 19.02 g formaldehyde were added. The mixture was stirred at 900 rpm with the temperature of 61°C for 4 hours. Next, the mixture was filtered, and the microcapsules were rinsed with ethanol and then left dry for at least 24 hours. The image of dried microcapsules was presented in **Figure 10.1**.

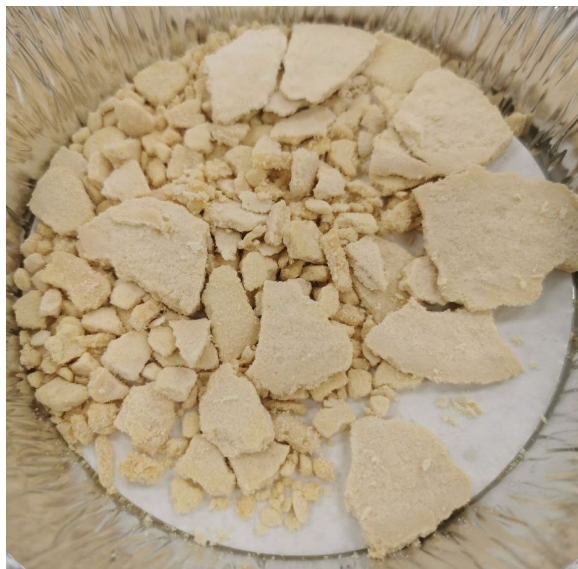


Figure 10.1: Dried LO microcapsules modified by MMT nanoclay.

RESULTS AND DISCUSSION

FTIR Analysis

All functional groups detected for the material MMT nanoclay are presented in **Figure 10.2**. The FTIR spectrum shows that there are more than five (5) absorption bands, which means that MMT nanoclay is a complex molecule. There is a broad absorption band detected from single bond region (2500 to 4000 cm^{-1}), indicating a presence of hydrogen bond. The presence of absorption peak detected at the wavenumber 3613.33, followed by narrow peak between 1000 to 1200 cm^{-1} , confirms the existence of nonbonded hydroxy group (-OH). There are a few peaks detected at triple region bond from 2000 to 2500 cm^{-1} , confirming the presence of $\text{C}\equiv\text{C}$ bond in the material. The peak detected at 2260.55 and 2201.80 corresponded to aliphatic cyanide/nitrile and $\text{C}\equiv\text{C}$ medial alkyne (disubstituted), respectively. The sharp peaks detected from 2000 to 2200 are assigned to common inorganic ions group such as Thiocyanate ion (2162.28 & 2168.62), and Isothiocyanate ion (2119.00, 2069.73 & 2012.87). In the double bond region (1500–2000 cm^{-1}), there are four (4) absorption bands presence. The peaks at 1987.30, 1970.02 and 1949.19 corresponded to transition metal carbonyls group, and the peak at 1632.92 corresponded to organic nitrates in nitrogen-oxy compounds. There is one peak identified in fingerprint region at 1026.30, which is assigned to organic silicone.

All functional groups detected for LO microcapsules modified by MMT nanoclay (3 wt%) were presented in **Figure 10.3**. There is a broad absorption band detected from single bond region (2500–4000 cm^{-1}), indicating there is hydrogen bond existing. A few absorption peaks above 3000 cm^{-1} indicate the existence of hydroxyl compounds. The first peak detected at 3339.28 corresponded to the normal ‘polymeric’ OH stretching. The second peak at 3010.90 confirmed the existence of simple unsaturated olefinic compounds. The third and fourth peak in single bond region at 2926.99 and 2854.74,

respectively, corresponded to methylene C-H stretching. There is a peak detected at triple region bond at the wavenumber of 2112, confirming the presence of $C\equiv C$ bond in the material. In the double bond region, a sharp peak at 1980.90 and 1745.17 corresponded to the active and simple carbonyl compounds, respectively. The peak at 1634.56 corresponded to alkenyl $C=C$ stretch (Olefinic). The peak at the wavenumber of 1557.58 confirmed the carboxylate of the carbonyl compound. The existence of methyl C-H bend was confirmed with the characterised peaks at 1465.93 and 1379.19. The peaks 1248.56 and 1165.65 corresponded to aryl -O stretch and secondary amine, CN stretch, respectively. Meanwhile, the peaks at 1103.75 and 1027.34 indicated the presence of organic siloxane (Si-O-C) and (Si-O-Si), respectively. The Si-O bonds confirmed the presence of MMT nanoclay in the microcapsules. There were also a few peaks detected at 841.61 and 772.40, declaring the existence of aromatic C-H out-of-plane bend. Lastly, the peak at 622.14 indicated the presence of alkyne C-H bend.

Optical Microscopy

The formation of microcapsules was first confirmed by optical microscopy, as shown in **Figure 10.4**. There are several spherical-shaped capsules detected with an average diameter of ca. 30 μm . The outer microcapsules wall exhibited quite a rough surface. In a polymerisation process, it is quite impossible to achieve a perfect dispersion and same size distribution at the same time (Azamian et al., 2022). It means that although the characterisation of each microcapsule is different, the average physical and chemical properties of the microcapsules could still be considered identical.

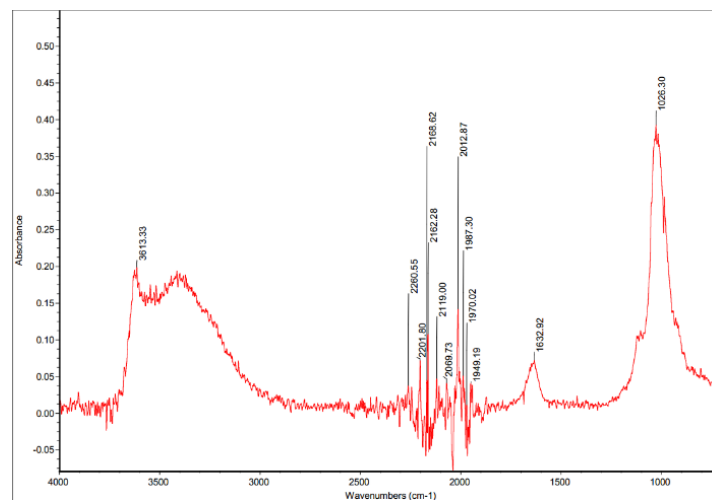


Figure 10.2: FTIR spectrum of MMT nanoclay.

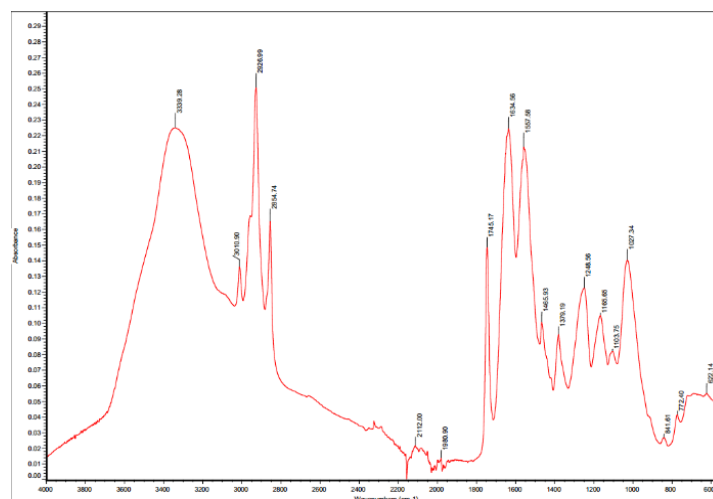


Figure 10.3: FTIR spectrum of microcapsule-based MMT nanoclay.

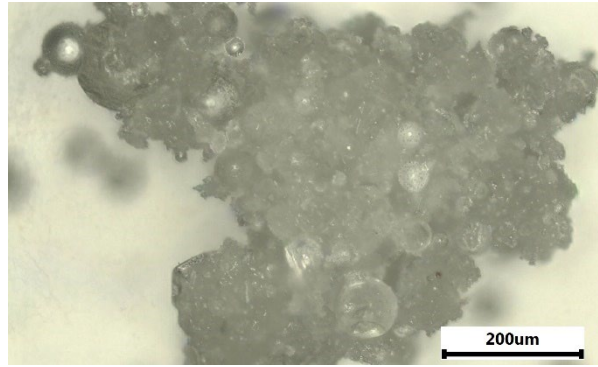


Figure 10.4: Microcapsules image from optical microscopy.

Scanning Electron Microscope (SEM)

The SEM image of the structure of LO microcapsules modified by MMT was presented in **Figures 10.5, 10.6** and **10.7**. The images were taken at various magnification levels and indicated that the microcapsules were indeed in spherical shape with rough tiny bumps on the surface. The average diameter of the microcapsules is 38.2 μm. The agglomeration occurred.

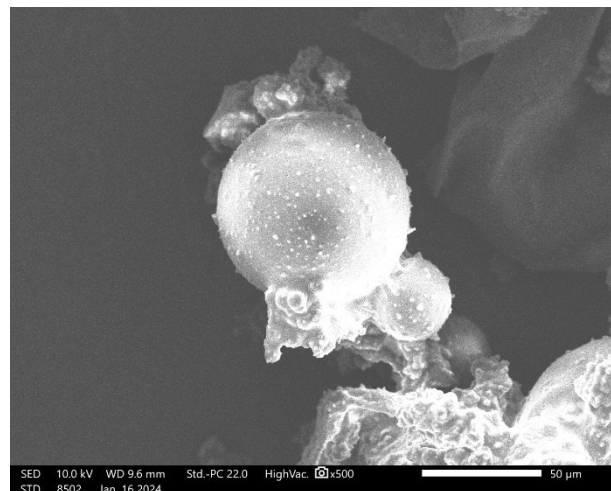


Figure 10.5: SEM image of microcapsules magnified at 500X.

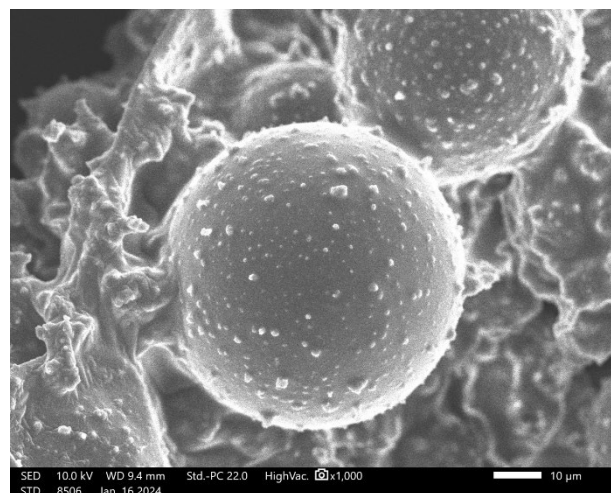


Figure 10.6: SEM image of microcapsules magnified at 1000X.

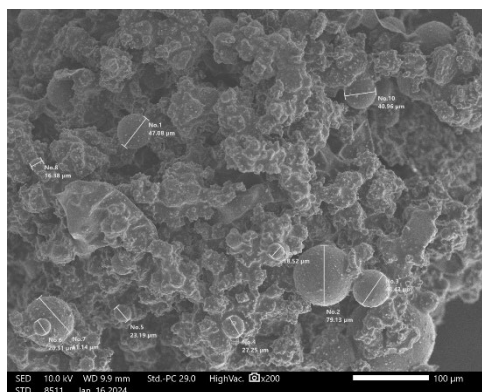


Figure 10.7: SEM image of microcapsules size.

CONCLUSION

The formation of microcapsules by in-situ polymerisation of LO and 3 wt% MMT nanoclay was successfully done. The FTIR spectrum evidently showed that MMT nanoclay is a complex molecule and it did exist in the modified LO microcapsules. Several sphere-shaped capsules were observed with rough surface on the outer wall.

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P11

Pilot Hole Optimisation in Dissimilar (7075-6061) Aluminium Alloy Friction Stir Spot Welding

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ABSTRACT

This research work presents the fabrication and research of dissimilar (7075-6061) aluminium joint by using Friction Stir Spot Welding process. Detail investigation is made on the influence of pilot holes on the mechanical response and microstructural of the metal joints under different welding parameters, which include pilot hole size, rotational speed and dwell time. Parameter analysis of the shear test results indicate that the specimen produced with pilot hole at size of 4 mm, rotational speed of 800 rpm and dwell time of 5 seconds have the maximum ultimate tensile strength of 89.29 MPa. This value is in close proximity to the calculated value of 80 MPa with 10% error. Optimum levels of the process parameters were analysed using the Taguchi parametric design approach. Through analysis of variance (ANOVA), the pilot hole size was the dominant contributing factor with 97%.

Keywords: Pilot Hole, Welding Parameter, Friction Stir Welding, Friction Stir Spot Welding

INTRODUCTION

Welding is a fabrication process that joins material, whereby two or more parts are fused together by means of heat, pressure or both, forming a joint as the parts cool (Zhang et al., 2020). During welding, the material or the parts to be welded are held securely together, often by clamping or jigging and the completed welded joint is known as weldment. There are two categories of welding which are fusion welding and solid-state welding (Ahmad et al., 2016). In fusion welding, the coalescence is accomplished by melting the two parts to be joined and in some cases adding, filler metal to the joint is needed. Examples of fusion welding are arc welding, oxyfuel gas welding and resistance spot welding. While for solid state welding, heat or pressure are used in order to achieve the coalescence, and the process is done below the melting temperature of the material. One of the most commonly used process in solid state welding is friction stir welding (FSW) due to its versatile application in various industries such as aerospace, automobile, railway and others (Heidarzadeh et al., 2021).

Friction stir welding (FSW) was first patented in 1991 by Thomas et. al. from ‘The Welding Institute’, England. This process is regarded as a new emerging technology to join various types of metals, ceramics, polymers and others (Ahmad et al., 2016) as well as joining different materials together to form dissimilar joints (Heidarzadeh et al., 2021). Friction Stir Spot Welding (FSSW) process was also tested successfully by The Welding Institute (TWI) in 1991 for joining Aluminium alloys and is a substitute of the FSW. It is eco-friendly and a process with minimal harm. **Figure 11.1** shows the schematic diagram of FSSW process (Uday et al., 2022).

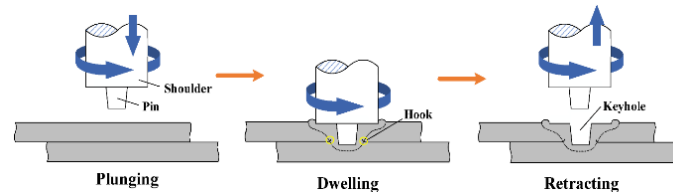


Figure 11.1: Schematic diagram of FSSW process

Joining different materials by using FSW or FSSW, is an advancement in joining technology. The advantages of dissimilar welding are enormous, such as energy efficiency, material optimisation and the ability to suit the materials properties according to specific areas (Li et al., 2022; Shah et al 2017). Among others, joining of aluminium (Al) – aluminium (Al) has recently received huge attention due to the unique properties of both materials. Individually, both metals are increasingly being used in automotive due to their numerous advantages such as light in weight, high specific strength and recyclability (Kayode et al., 2021).

In friction welding (FRW) process, no external heat is supplied and the joint formation takes place due to diffusion at the interface surfaces under high-pressure force and frictional heat along the length of the tool. However, since a high-pressure force is applied in order to form a metal-to-metal joint, excessive force and heat may occur occasionally (Mishra et al., 2005; Shen et al., 2015). Thus, it will affect the workpiece as well as the mating surfaces, which is the rotating tool and workpiece' surface. As a result, the product will have defect, low mechanical properties and reduced tool life (Hussain et al., 2019; Eslami et al., 2015; Papahn et al., 2015).

Consequently, one of the most effective ways to reduce the amount of excessive force and heat during the process is by making a pilot hole since it is designed to reduce the amount of force imposed on the tool. Pilot hole, also known as pre-hole or clearance hole, is a through hole that is usually made or machined at the beginning of a weld (Tsao, C. C., 2006; Costas et al., 2021). Accordingly, a drill operation is used to make a pilot hole, where a drill bit is used to make a circular hole on the workpiece. Besides reducing excessive force, this method also offers other benefits such as the ability to reduce the risk of delamination, which indirectly helps to improve the surface finish, increase the tool life and reduce the energy consumption in a joining process (Tsao, C. C., 2006; Costas et al., 2021; Binali et al., 2022).

Table 11.1 highlights the recent progress of pilot hole optimisation in various joining processes, mainly focusing FRW processes in chronological. It can be noted that the publication rate in this area steadily increases for the past decade. A growing number of works have covered the pilot hole topics especially in FSW and FSSW processes, owing to the fact that this method is suitable for many metal types and in combining dissimilar metals (Khalafe, W. H et al., 2022; Zhikang. S et al., 2019). Thus, Table 11.1 presents the papers related to the pilot hole optimisation study in chronological order from 2014 to 2024.

Table 11.1: Pilot hole optimisation in chronological order from 2014 to 2024.

No.	Authors	Year	Method	Material
1	Jingjing Li	2014	Ultrasonic welding friction stir blind riveting and Frictions stir spot welding	Aluminium, copper and magnesium
2	Galya Duncheva	2015	Welding and mandrel cold working method	S355 steel welded stiffened plate
3	Xinjiang Fei	2016	Laser-assisted friction stir welding	Q235 steel and 6061-T6 aluminium alloy

No.	Authors	Year	Method	Material
4	Hossein Karami	2017	Threaded Hole Friction Spot Welding (THFSW)	AA5052 Aluminium polymer composite hybrid
5	Moslem Paidara	2019	Friction-Stir-Spot-Welding (FSSW)	AA2219 and PP-C30S sheets
6	Yang Gao	2020	Pre-hole Friction Stir Spot Welding	AA2219 and AA3003 sheets
7	S.Venkadesh	2021	Friction stir welding	AA2024 and AA6061
8	Osamah Sabah Barrak	2022	Friction Stir Spot Welding	Pure Copper (C11000) and AA5052
9	Qiaoying Zhou	2023	Flow-drill screw and friction stir welding joints	AA6061-T6 and DP590 high-strength steel plates
10	James Koch	2024	Friction-stir welding	Similar metal and alloys

Based on the increasing use of the pilot hole techniques in previous works, it proved that pilot hole drilling has been widely studied and used in industrial production (Yazdi et al., 2019). Hence, this research work presents the fabrication and research of dissimilar (7075-6061) aluminium joint by using FSSW process. Detailed investigation made regarding the influence of pilot holes on the mechanical response and microstructural of the metal joints under different welding parameters includes pilot hole size, rotational speed and dwell time. The scope of the research mainly focuses on the implementation of pilot holes in FSSW processes and evaluation on the effects of welding parameters to the process variables and material response.

RESULTS AND DISCUSSION

The welding process utilises aluminium alloy AA7075 and AA6061, with a dimension of 100 mm × 30 mm × 3 mm. To create pilot holes in the workpiece, drill bits with diameters of 2 mm, 4 mm, and 6 mm were selected. Friction stir spot welding were used to fabricate the dissimilar weld joint. The joining process was carried out by using VMM3917 partner vertical milling machine, as depicted in **Figure 11.2**.



Figure 11.2: VMM3917 partner vertical milling machine

In order to investigate the optimum welding parameters, a Taguchi method and analysis of variance (ANOVA) was utilised. Data used to conduct the analysis were obtained from the shear test which been carried out by using an Instron universal tensile test machine with a crosshead speed of 1 mm/min. The main parameters to observe are pilot hole size, rotational speed and dwell time. **Table 11.2** shows the three levels for the three factors.

Table 11.2: Levels of parameter used in experiment

Factors	Pilot Hole (mm)	Rotational Speed (rpm)	Dwell time (s)
Level 1	4	800	5
Level 2	5	1000	10
Level 3	6	1200	-

Figure 11.3 shows the cross-section schematic setup diagram of friction stir spot welding process with pilot hole, while **Figure 11.4** shows the top view weld appearance representation of a completed spot-welded sample. The specimen was prepared using parameters at level 1, with rotational speed of 800 rpm, dwell time of 5 s and pilot hole size at 4 mm. All samples show similar observations of good spot-weld appearance with minimal flash. However, the use of a larger diameter pilot hole leads to an incomplete back filling.

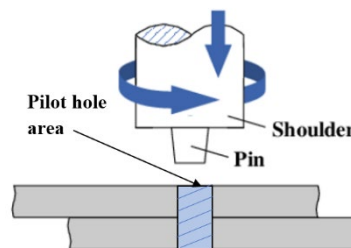
**Figure 11.3:** Schematic setup diagram of friction stir spot welding process with pilot hole**Figure 11.4:** Top view weld appearance representation of a completed spot-welded sample with parameters at level 1

Table 11.3 summarises the shear strength mean value and S/N ratio for all conditions. single spacing for main document. From the shear test result, the larger-the-better S/N ratio was calculated using equation shown in **Figure 11.5**, where n is the number of tests and Y_{ijk} is the experimental value of the i_{th} quality characteristics in the j_{th} experiment at the k_{th} test.

Table 11.3: Shear strength mean value and S/N ratio

Input Parameter			Output (mean)	
Pilot hole	Rotational speed (rpm)	Dwell Time (s)	USS (MPa)	S/n ratio
4	800	5	89.29	48.77
4	800	10	85.44	48.40
4	1000	5	73.60	46.93
4	1000	10	73.34	46.92
4	1200	5	70.57	44.85
4	1200	10	67.60	44.45
5	800	5	58.09	44.96
5	800	10	64.46	45.78
5	1000	5	66.52	46.14
5	1000	10	44.81	42.62
5	1200	5	42.32	42.23
5	1200	10	45.62	42.96
6	800	5	29.94	34.34
6	800	10	27.01	38.27
6	1000	5	38.51	41.30
6	1000	10	45.54	44.51
6	1200	5	43.09	44.34
6	1200	10	41.31	42.12

$$\eta_j = -10 \lg \left(\frac{1}{n} \sum Y_{ijk}^2 \right)$$

Figure 11.5: S/N ratio formula

Based on the overall results in Table 11.3, the analysis has shown the highest USS and the best parameter levels to achieve maximum shear strength (highlighted in bold), which is level 1. Next, through ANOVA analysis, the optimum value of the shear strength can be calculated using equation in **Figure 11.6**, where PH_1 is the average shear strength at 4 mm pilot hole size; RS_1 is the average shear strength at rotational speed of 800 rpm; DT_1 is the average shear strength at dwell time of 5 s; and T is the overall mean of the shear strength. By substituting the values calculated from Table 11.3, the highest shear value was calculated to be 80 MPa. Compared to the experimental highest value 89.29 MPa, the error was only 10% and the pilot hole size was the dominant contributing factor with 97%.

$$(PH_1 + RS_1 + DT_1) - 2T = 79.55 \text{ MPa}$$

Figure 11.6: Parameter analysis equation

To summarise the USS value obtained from the test, **Figure 11.7** presents the data which have been tabulated in **Table 11.3**. In terms of the relationship of USS and pilot hole size, all specimens generally show a decrease in the USS value when the pilot hole size (mm) is increased.

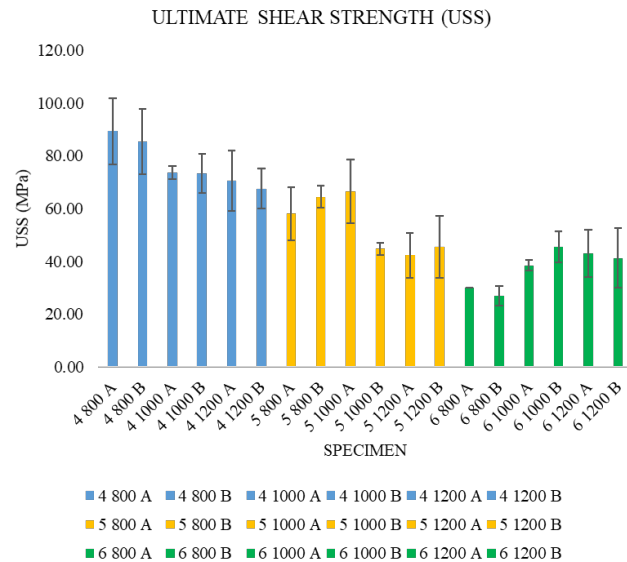


Figure 11.7: Bar Graph of Ultimate Shear Strength (MPa)

CONCLUSION

Dissimilar (7075-6061) aluminium joint were fabricated by using friction stir spot welding (FSSW) process to investigate the influence of pilot hole on the mechanical response and microstructural of the metal joints under different welding parameters which include rotational speed and dwell time. From the parameter analysis by using Taguchi method, the shear test results indicate that the specimen produced with pilot hole at size of 4 mm, rotational speed of 800 rpm and dwell time of 5 s, has the maximum ultimate tensile strength of 89.29 MPa. This value is in close proximity to the calculated value of 80 MPa with 10% error. Through analysis of variance (ANOVA), the pilot hole size was the dominant contributing factor with 97%. Further analysis is still in progress and will be reported onwards.

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P12

Simulation Analysis of Free Piston Hydrogen Internal Combustion Engine Performance

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ABSTRACT

Using MATLAB/Simulink, a dynamic and thermodynamic model is developed for a free-piston hydrogen internal combustion engine. A state machine is employed to describe the discrete states and events during the operating process, and numerical simulations are conducted to study the effects of ignition timing and equivalence ratio on the performance of the free-piston hydrogen internal combustion engine. The simulation results indicate that retarding the ignition timing appropriately helps improve the indicated power and indicated thermal efficiency of the free-piston hydrogen internal combustion engine. Increasing the equivalence ratio enhances the compression ratio and operating frequency of the engine, resulting in a significant increase in indicated power. The indicated thermal efficiency reaches its peak at an equivalence ratio of 0.7.

Keywords: free-piston, hydrogen fuel, internal combustion engine, indicated power, indicated thermal efficiency

INTRODUCTION

In the era that focuses on energy conservation and environmental sustainability, researchers are continuously developing more efficient powertrains for vehicles to reduce fuel consumption and emissions. In comparison to traditional crankshaft-based internal combustion engines, free-piston internal combustion engines (Hung & Lim, 2016) eliminate the crank-connecting rod mechanism and flywheel inertial device. They couple the internal combustion engine with a linear generator, utilising the reciprocating motion of the free piston for direct power generation. This design offers advantages such as variable compression ratio, strong fuel adaptability, high power-to-weight ratio, and shorter energy transfer paths. Therefore, it is more suitable as an internal combustion power generation device for hybrid vehicles.

This study focuses on a two-stroke free-piston hydrogen internal combustion engine (Hanipah et al., 2015). A numerical computational model is established using MATLAB/Simulink to simulate and analyse the system's operation and the influence of system parameter changes on performance. The results and discussion section presents a comparative analysis of the piston acceleration and cylinder pressure at different crankshaft angles for the free-piston hydrogen internal combustion engine, crankshaft-based hydrogen internal combustion engine, and free-piston gasoline engine during steady-state operation.

RESULTS AND DISCUSSION

Using the same model parameters, a comparative analysis was conducted on the piston acceleration and cylinder pressure at different crankshaft angles for the free-piston hydrogen internal combustion engine (Ngwaka et al., 2021), crankshaft-based hydrogen internal combustion engine, and free-piston gasoline engine under steady-state operating conditions.

The simulation results of the performance variation of the free-piston hydrogen internal combustion engine (Li et al., 2023) at different ignition timings. From **Figure 12.1**, it can be observed that when the ignition timing is set between 26 and 28 mm, the peak cylinder pressure increases as the ignition timing is delayed. The highest peak cylinder pressure of 3.7 MPa is observed at an ignition timing of 28 mm. When the ignition timing is further delayed to 29 mm, the peak cylinder pressure slightly decreases. However, when the ignition timing is set at 30 mm, the piston cannot reach the ignition position, resulting in system misfire and stoppage.

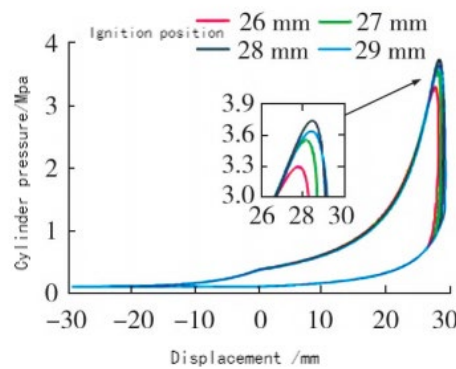


Figure 12.1: Simulation results of cylinder pressure changes of free piston hydrogen internal combustion engine under different ignition positions

From **Figure 12.2**, it can be observed that as the ignition timing is delayed, the compression ratio gradually increases from around 6.0 to 7.5. The system operating frequency initially increases and then decreases, ranging from 21.5–22.5 Hz. When the ignition timing is set at 26 mm, the operating frequency is relatively low. When the ignition timing is set between 27 and 28 mm, the system operating frequency is higher. However, when the ignition timing is delayed to 29 mm, the operating frequency decreases. The reason for this is that at an ignition timing of 26 mm, the lower cylinder pressure leads to a lower operating frequency. When the ignition timing is delayed to 29 mm, the free piston experiences a significant decrease in speed during the compression process near the top dead centre, resulting in an extended compression process and a lower operating frequency.

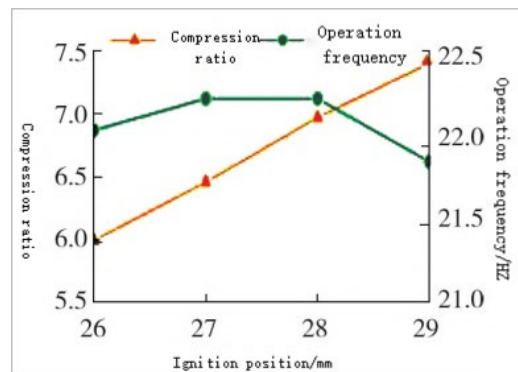


Figure 12.2: Simulation results of compression ratio and operation frequency changes of free piston hydrogen internal combustion engine under different ignition positions

It can be seen from **Figure 12.3** that as the ignition position is pushed back, the indicated thermal efficiency increases from 36.8% to 40.2%. The indicated power continues simulation results of cylinder pressure changes of free piston hydrogen internal combustion engine under different ignition positions to increase with the increase of the indicated thermal efficiency, but when the ignition position is pushed back from 28 mm to 29 mm, the indicated power does not change significantly. The reason for the analysis is that, as the ignition position is pushed back, the compression ratio the thermal efficiency continue to increase, the hydrogen fuel burns quickly, and the combustion process has a high isovolumetric capacity. When the ignition position is pushed back, there is no afterburning in the free piston gasoline engine. In a serious situation, the indicated thermal efficiency continues to increase; when the ignition position is pushed back to 29 mm, due to the decrease in operating frequency, the indicated power is around 1.2 SW, with no significant change.

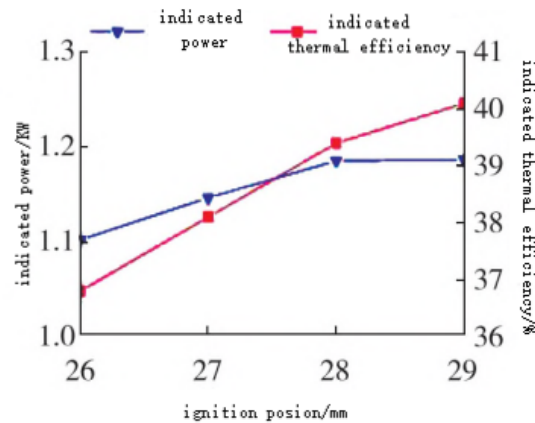


Figure 12.3: Simulation results of indicated power and indicated thermal efficiency changes of free piston hydrogen internal combustion engine under different ignition positions

It can be seen from **Figure 12.4** that as the fuel-to-air equivalence ratio increases, the operating frequency increases from 22.3 Hz to 36.6 Hz, and the compression ratio gradually increases from 7 to about 12. When the fuel-to-air equivalence ratio exceeds 0.7, the compression ratio increase decreases. The reason for the analysis is that, as the fuel-air equivalence ratio increases, the average piston speed accelerates, and the operating frequency increases; because the moving component moves faster at the midpoint position, and the system will have more kinetic energy converted into compression potential energy during the compression process, resulting in the compression ratio increases.

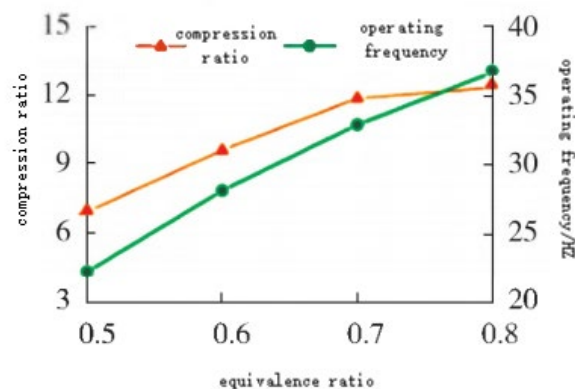


Figure 12.4: Simulation results of changes in compression ratio and operating frequency of a free-piston hydrogen internal combustion engine under different fuel-air equivalence ratios

It can be observed from **Figure 12.5** that the indicated power increases significantly from 1.2 kW to 3.3 kW as the fuel–air equivalence ratio increases. The indicated thermal efficiency initially increases and then decreases with the increase in equivalence ratio. The highest indicated thermal efficiency of 43.8% is obtained at a fuel–air equivalence ratio of 0.7. When the equivalence ratio increases further to 0.8, the indicated thermal efficiency slightly decreases to 42.6%. As the fuel–air equivalence ratio increases, the operating frequency of the engine increases, which contributes to the significant rise in indicated power. In addition, a moderate increase in the equivalence ratio accelerates the combustion rate of hydrogen fuel, thereby improving thermal efficiency during the compression and combustion processes. However, a further increase in the fuel-to-air equivalence ratio causes the moving components to move at a higher speed during the compression process. After reaching the ignition position, there is still a large residual kinetic energy and negative compression work.

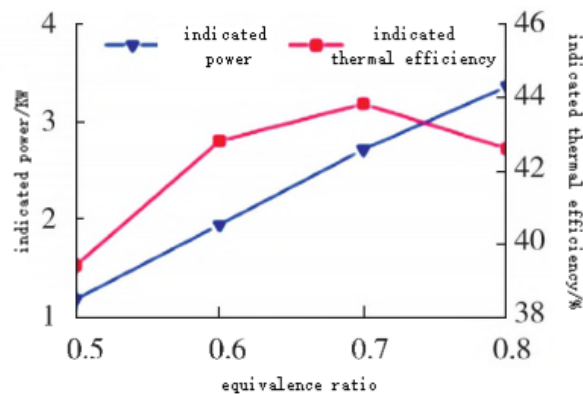


Figure 12.5: Simulation results of changes in indicated power and indicated thermal efficiency of a free-piston hydrogen internal combustion engine under different fuel-air equivalence ratios

CONCLUSION

Through MATLAB/Simulink, a dynamic and thermodynamic model of the free-piston hydrogen internal combustion engine was established to analyse the effects of ignition timing and air-fuel ratio on the engine's performance. Properly delaying the ignition timing helps to improve the indicated power and indicated thermal efficiency of the free-piston hydrogen internal combustion engine. However, excessively delaying the ignition timing can lead to misfire and engine shutdown. Increasing the air-fuel ratio can increase the compression ratio and operating frequency of the free-piston hydrogen internal combustion engine. It significantly increases the indicated power, but the indicated thermal efficiency does not continuously increase with the increase in compression ratio. The maximum indicated thermal efficiency is achieved at an air-fuel ratio of 0.7.

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P13

Investigation of Denoising Methods to Minimise Data Discrepancies for Clustering Analysis of Acoustic Signal & Optical Spectra from Different Weld Penetration Conditions.

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ABSTRACT

The clustering analysis in laser beam welding encounters challenges in discerning distinct features due to the interference from noise, originating primarily from spatter. This study aims to investigate the effectiveness of several denoising methods, such as Empirical Mode Decomposition (EMD), EMD-based Statistical Threshold, Variational Mode Decomposition (VMD), Bandpass Filter, and Moving Average, in minimising noise within acoustic signal and optical spectra. The methodology includes the process of feature extraction, feature selection, and feature analysis acquired from acoustic signal and optical spectra. The selection of an appropriate denoising method depends on the distinct distribution of Log Diff. Mean Abs. Value and Principal Component 1 in the data. The findings indicate that EMD with Standard Deviation threshold and Moving Average proves effective in minimising data discrepancies in acoustic signal and optical spectra, offering a fresh perspective in addressing noise within a limited wavelength spectrum, specifically in classifying different weld penetration conditions.

Keywords: Empirical Mode Decomposition, Statistical Threshold, Denoising Methods, Acoustic Signal, Optical Spectra

INTRODUCTION

The clustering analysis of acoustic signal and optical spectra, especially in the presence of various weld penetration conditions, is made more challenging by the inherent noise caused by spattering (Xia et al., 2019, Huang & Kovacevic, 2009, Yang et al., 2008) which worsens the distinctions in the distribution of features within acoustic signal and optical spectra, leading to a decreased efficiency in distributing signal features. The challenging difficulties of distinguishing features based on different weld penetration conditions leads to the idea that denoising methods could improve the observed variations in feature distribution (Jiao et al., 2023, Cui et al., 2020). The present study fills the gap in current research by providing fresh perspectives on the application of existing denoising methods in the field of laser beam welding, specifically in relation to acoustic signals and optical spectra.

Additionally, denoising methods are crucial for minimising discrepancies in the data, which improves the precision of clustering analysis (Ding, 2022, Lv et al., 2017, Huang & Kovacevic, 2009). This investigation aims at examining several denoising methods, including Empirical Mode Decomposition (EMD), EMD-based Custom Thresholding, Variational Mode Decomposition (VMD), Bandpass Filter, and Moving Average, to assess their efficacy for reducing noise in acoustic signal and optical spectra data.

EMD, a method in signal processing, decomposes a signal into Intrinsic Mode Functions (IMFs), where each IMF represents a distinct frequency component. Applying Empirical Mode Decomposition (EMD) to denoise acoustic signal data requires removing Intrinsic Mode Functions (IMFs) that contain

noise (Gao et al., 2022, Cheng et al., 2018). Nevertheless, it is crucial to acknowledge that the computing costs linked to EMD may make it less viable for large datasets. In addition, an EMD-based Statistical Threshold is a signal pre-processing method which employs a statistical thresholding technique to eliminate noise from intrinsic mode functions (IMFs) (Yusof et al., 2023, Mohguen and Bekka, 2017, Boudraa et al., 2004). This method could be an effective and feasible way for reducing noise in acoustic signal data. Besides that, VMD is a signal pre-processing approach that breaks down a signal into oscillatory modes, each representing a different frequency component. It has proven effective in reducing noise from acoustic signal data by eliminating the modes that include noise (Luo et al., 2023, Shi et al., 2021, Chen et al., 2019).

On the other hand, a bandpass filter operates based on signal pre-processing principles to allow only a specific frequency range to pass through while reducing frequencies that are outside of this range. Applying bandpass filters to denoise acoustic signal data entails eliminating frequencies that include noise (Cai et al., 2022, Fidali, 2018, Shelyagin et al., 2018, Kim & Ahn, 2012). Nevertheless, it is crucial to acknowledge that bandpass filter may exhibit constraints in eliminating noise that is dispersed across a broad frequency spectrum. Besides that, Moving Average is a signal pre-processing method that calculates the mean value inside a sliding window of data points (Goodwin et al., 2022, Maghraby, 2014, You et al., 2014). It may be used as a tool to remove noise from optical spectra data by creating a smoother representation. However, its effectiveness may be compromised when faced with noise distributed widely across the wavelength spectrum.

The denoising methods from the previous study have the potential to minimise discrepancies of data in clustering analysis of acoustic signal and optical spectra associated with various weld penetration conditions. The selection of an appropriate method depends on the distinctive features of data distribution. EMD-Based Custom Thresholding and VMD are effective methods for mitigating noise in acoustic signal. Simultaneously, the application of Moving Average can provide fresh perspective in addressing noise distributed across a limited wavelength spectrum, specifically in the field of laser beam welding.

METHODOLOGY

The methodological approach of this study includes feature extraction, feature selection, and analysis of features derived from acoustic signals and optical spectra. **Figure 13.1** shows that the methodology begins by obtaining the initial acoustic signal and optical spectra, then extracting 12 pertinent features from these signals through time and wavelength domain. Following that, a meticulous procedure of selecting features is carried out to choose the most relevant traits for subsequent methodology.

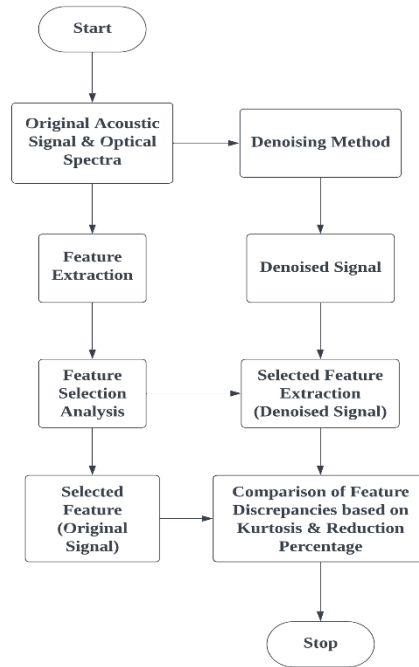
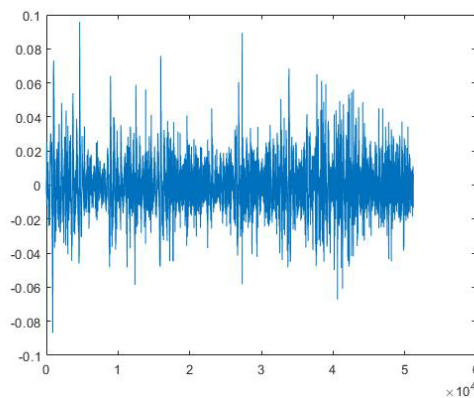


Figure 13.1: The flowchart of the investigation of denoising methods on acoustic signal and optical spectra

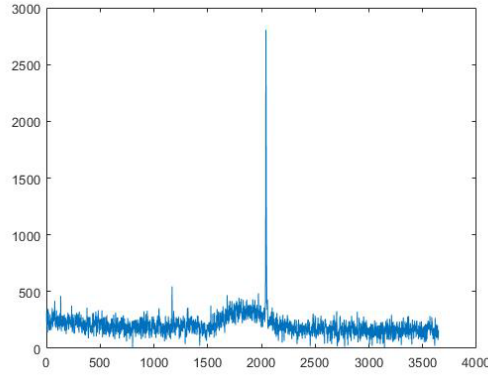
The subsequent methodology outlines the procedure for reducing noise in the signal using an appropriate method and extracting features from the denoised signals. The methodology focuses on comparing the differences between the two selected features from the original signal and those from the denoised signal based on kurtosis and reduction percentage of dispersion size. Ultimately, the effect of denoising methods on acoustic signal & optical spectra is shown in the next section which results in a thorough and evaluative framework for the process of extracting and analysing features.

RESULTS AND DISCUSSION

The acquisition and examination of the original acoustic signal and optical spectra provide evidence of noise produced by spatter, as shown in **Figure 13.2**.



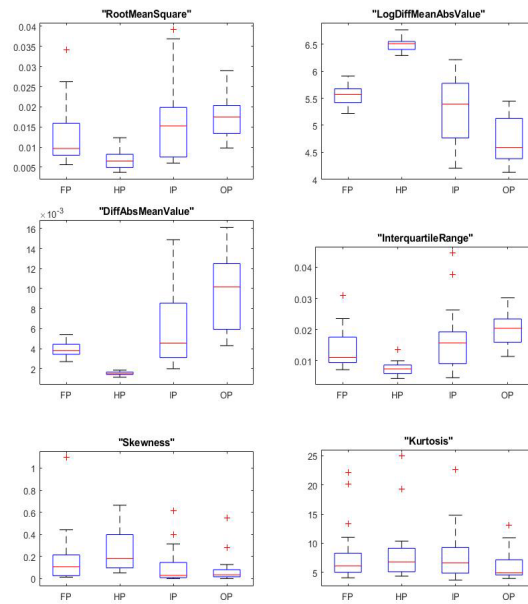
(a)



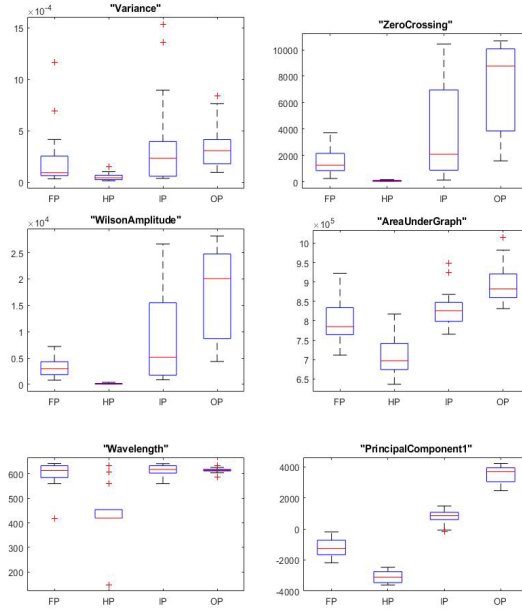
(b)

Figure 13.2: Acquired Signal: (a) Acoustic Signal, (b) Optical Spectra

Boxplots were generated to visualise the overlap between each weld penetration condition by extracting 12 features from the acquired signal. The results are presented in **Figure 13.3** and **Table 13.1**. The acoustic signal yields nine (9) extracted features, namely Root Mean Square (RMS), Log Different Mean Absolute Value (LDMAV), Different Absolute Mean Value (DAMV), Interquartile Range, Skewness, Kurtosis, Variance, Zero Crossing, and Wilson Amplitude (WAMP). On the other hand, optical spectra covered three (3) features, the area under graph, wavelength, and Principal Component 1. The selection of these attributes was based on their strong correlation with weld penetration conditions in laser and arc welding process. (Xinqiang et al., 2020, Lee et al., 2020, Olsson, 2019, Too et al., 2019a, Too et al., 2019b).



(a)



(b)

Figure 13.3: Boxplot of features based on penetration condition:

(a) RMS, LDMAV, DAMV, Interquartile Range, Skewness and Kurtosis, (b) Variance, Zero Crossing, WAMP, Area under Graph, Wavelength and Principal Component 1

A boxplot is a useful method for visually representing a dataset that has several data points within a given range (Krzywinski & Altman, 2014). The boxplot in this study facilitates comprehension of the discrepancies in features being observed, as well as the spread of the data for each weld penetration condition.

Table 13.1: The overlap in the boxplot of features based on different weld penetration conditions

Features	Overlap
Root Mean Square	4
Log. Diff. Mean Abs. Value	3
Diff. Abs. Mean Value	3
Interquartile Range	4
Skewness	4
Kurtosis	4
Variance	4
Zero Crossing	4
Wilson Amplitude	3
Area Under Graph	4
Wavelength	4
Principal Component 1	0

Table 13.1 demonstrates that four (4) features were prioritised due to having less overlap in their distribution. These features include LDMAV, DAMV, and WAMP from the acoustic signal, as well as Principal Component 1 from the optical spectra. The analysis examines dispersion trends and patterns in scatter plots to identify the most relevant features of the weld penetration conditions.

The Log Diff. Mean Abs. Value with Principal Component 1 scatter plot, shown in **Figure 13.4**, displays favourable trends and patterns. The dispersion of Incomplete Penetration and Overheat Penetration exhibited more precision and reduced variability in the data. On the other hand, the

distribution of Half Penetration exhibited a more circular pattern in terms of data precision compared to the other features. Moreover, Full Penetration exhibited distinct variations in trends and patterns during this comparison, suggesting a decrease in the extent of dispersion.

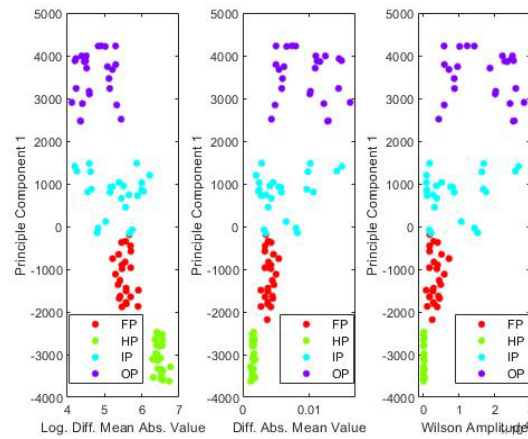


Figure 13.4: Scatter plot of LDMAV, DAMV, WAMP with Principal Component 1

Following that, **Table 13.2** presents a comparison between the original and denoised signals using kurtosis as the basis. Kurtosis quantifies the degree to which the data deviate from a normal distribution, indicating whether the data has heavy or light tails. Data sets with high kurtosis are characterised by the presence of heavy tails or outliers, whereas low kurtosis are characterised by light tails or a lack of outliers (Loperfido, 2020, Bastianin, 2020).

Table 13.2: Comparison of kurtosis for original and denoised signals based on different weld penetration conditions

Signal	Kurtosis	FP	HP	IP	OP
Acoustic	Original	5.5	7.9	6.6	4.4
	EMD ZScore	3.5	3.3	3.1	2.8
	EMD SD	2.6	2.5	2.3	1.8
	EMD IQR	2.5	2.4	2.4	1.9
	EMD	7.2	34.2	6.6	4.4
	VMD	4.2	51.2	5.9	2.9
	Bandpass Filter	5.3	70.1	7.3	3.7
Optical	Original	195.9	228.6	99.6	79.6
	Moving Average	32.1	45.5	15.7	12.2
	VMD	257.9	260.4	148.1	110.8

According to **Table 13.2**, the kurtosis values for the EMD with Standard Deviation and Interquartile Range thresholds are low, indicating light tails or a lack of outliers. Both methods are regarded as effective for removing noise from acoustic signals. Concurrently, the Moving Average demonstrated promising effectiveness in reducing noise in the optical spectra.

Furthermore, **Figure 13.5** presents a scatter plot that illustrates the comparison of trends and patterns between the original data, EMD SD + MA, and EMD IQR + MA. To identify the most effective denoising techniques for acoustic signals and optical spectra in various weld penetration conditions, a comparative analysis of the reduction percentage in dispersion size using the selected features of EMD

SD + MA and EMD IQR + MA were conducted. The findings of this comparison are presented in **Table 13.3**.

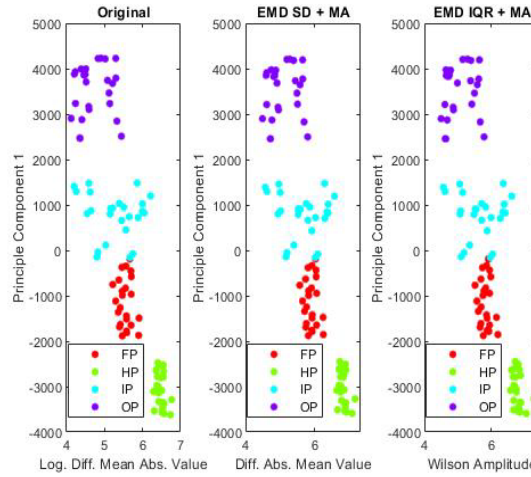


Figure 13.5: Scatter plot of selected features from Original, EMD SD + MA and EMD IQR + MA signals based on different weld penetration conditions

Table 13.3: Comparison of reduction percentage from original and denoised selected features dispersion size

Axis	Weld Condition	EMD SD + MA (%)	EMD IQR + MA (%)
X - axis	FP	-0.04	-444.91
	HP	-12.38	-44.41
	IP	0.19	-2.41
	OP	0.84	2.31
Y - axis	FP	0.45	42.60
	HP	0.37	-72.78
	IP	0.51	1.41
	OP	0.43	0.36

Table 13.3 demonstrates that the EMD SD + MA method produced a greater number of decreases in percentage from the original and denoised selected features dispersion size. The efficacy of denoising methods for acoustic signal and optical spectra, particularly in laser beam welding, is demonstrated using EMD with Standard Deviation thresholding and Moving Average.

CONCLUSION

The denoising methods investigated in this study aim to reduce data discrepancies in the clustering analysis of acoustic signal and optical spectra related to various weld penetration conditions. The study offers valuable insights into the application of EMD-based Custom Thresholding, an existing denoising method, for the purpose of reducing noise in acoustic signal while Moving Average is identified as an effective method for reducing noise across a limited wavelength spectrum in optical spectra within the context of laser beam welding.

In summary, the present study contributes to bridging gaps in the application of denoising methods in laser beam welding, mainly focusing on acoustic signal and optical spectra. The findings highlight the significance of selecting appropriate denoising method based on the distinctive feature distribution

of data, thereby enhancing the accuracy of clustering analysis when dealing with various weld penetration conditions.

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P14

Oscillatory Flow Analysis in Thermoacoustic Refrigeration Using PIV

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ABSTRACT

Concerns about global warming and the thinning ozone layer have led to the search for refrigeration systems that are kinder to the environment. Thermoacoustic refrigeration (TAR) is one of the systems that has drawn attention due to its energy efficiency, lack of harmful substances, and quieter operation compared to regular refrigerators. This study investigated on how TAR works by explaining the process of turning sound into heat to make things cold in the resonator. The stack, a crucial part of the system, is the core of how TAR works, and its effectiveness determines how well the system performs. Although many studies have focused on improving the stacks, recognising their role as the system's core, understanding how the air moves is critical to achieving optimal performance. While computer simulations are standard, there is still a need for more hands-on experiments. Recent studies have shown that swirling air can disrupt the system, so Particle Image Velocimetry (PIV) was used to examine how quickly the air moves in different parts of a TAR system. The goal was to understand how the air moves to improve the system's performance. The experiment utilised a small TAR system with a resonator, a stack, and a speaker. PIV was used to observe how the air moves without disturbing it. Laser-made fog was used to monitor how the air flowed in the resonator. This study explained how the experiment was carried out, the location of the PIV tool, how pictures were taken, and how a computer was used to determine the air's velocity. The results provide insights into how the air behaves and lay the foundation for improving TAR systems.

Keywords: Thermoacoustic refrigeration, Particle Image Velocimetry, Oscillating flow, Eco-friendly refrigeration.

INTRODUCTION

Owing to the concern of global warming and depletion of ozone layers in recent years, there has been a considerable increase in the demand for effective and ecologically friendly refrigeration systems. (Xiao, Gu & Zhang, 2020). Unlike the traditional vapour compression refrigeration systems, thermoacoustic refrigeration (TAR) has shown promise and benefits, including a lack of hazardous refrigerants and reduced noise levels.

To support the benefits, it is more apparent that the only components needed for a TAR system are the stack, resonator, speaker, heat and cold heat exchanger, and the non-flammable gas as the working fluid. The arrangement of the components is explained in **Figure 14.1**. From the element itself, no moving component makes it less noisy. Unlike the refrigerant used by traditional vapour compression refrigeration systems, TAR uses a mixture of inflammable inert gas. However, TAR is used impractically because of its low efficiency compared with conventional vapour compression refrigeration. (Biwa, 2021; Chase, 1995; Girgin & Türker, 2012; Ward et al., 2017)

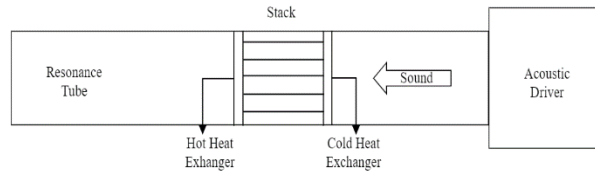


Figure 14.1: The components of TAR

The basic concept behind thermoacoustic refrigeration combines pressure, displacement, and temperature oscillations. Combining these three oscillations and their interaction with solid boundaries produces the thermoacoustic effect. Starting with the acoustic driver delivers acoustic power to the resonator (resonance tube) that holds the stack. Along the stack, the gas particle also oscillates when the acoustic wave oscillates because of the nature of their movement.

The movement of the gas is illustrated in **Figure 14.2**. Acoustic waves are generated due to the compression and expansion processes experienced by the gas within the system. During adiabatic compression, the temperature of the gas increases and becomes higher than the surrounding stack temperature. As a result, heat is transferred from the gas to the stack. Conversely, during adiabatic expansion, the gas temperature decreases below the surrounding stack temperature, causing the gas to absorb heat from the stack (Wang et al., 2020). Since this thermoacoustic heat exchange process occurs primarily within the stack, the stack is widely regarded as the heart of the thermoacoustic refrigerator (TAR). Consequently, many researchers have focused on improving the design and performance of the stack to enhance the overall efficiency of TAR systems (Alamir, 2019; Babu & Sherjin, 2018; Prashantha et al., 2022).

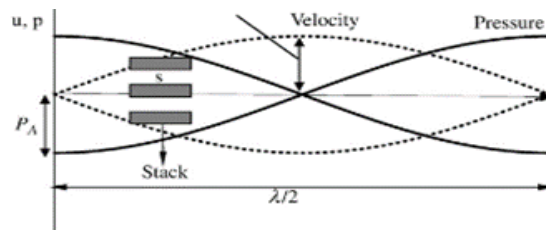


Figure 14.2: Sinusoidal of standing wave

Understanding the interaction between fluid flow and energy transfer can be complex when it involves an oscillatory flow of an acoustic wave and a solid material with a porous structure. It is crucial to comprehend the underlying flow dynamics and velocity distribution to achieve optimal performance and enhance the overall effectiveness of TAR.

A recent study by Allafi et al. (2021) significantly contributed to unravelling this complex flow phenomenon. They employed two-dimensional ANSYS FLUENT CFD to investigate the flow in the TAR system. By utilising two different frequencies, they observed temporal variations in velocity at the end of the stack. Furthermore, they identified the appearance of two vortex layers at the exact location. This discovery sheds light on one of the reasons behind the inefficiency of heat transfer in TAR, attributing it to the presence of vortices that disrupt the heat transfer flow.

Additionally, Zhang et al. (2013) encountered a comparable scenario at the stack's terminus in their investigations. Their findings led to the conclusion that the presence of vortices impacts both pressure and velocity. Given that a smooth and fluid oscillatory flow would be more advantageous, it is worth noting that the current theoretical framework, as proposed by Rott, relies on the linear theory of acoustics, assuming laminar flow inside the resonator. This assumption may introduce a discrepancy between theoretical predictions and system behaviour. (Zahari et al., 2022)

Therefore, it becomes imperative to delve into the relationship between oscillatory flow and the heat transfer processes within the resonator. Such a study holds vital importance as it has the potential to enhance the overall system efficiency by addressing and mitigating any deviations from the theoretical predictions.

There are various approaches for acquiring reliable flow characteristic information (velocity profile, temperature distribution, and pressure) to conduct in-depth quantitative measurements in thermoacoustic systems. Past researchers have employed two main methods for measuring velocity profiles: simulation-based and experimental-based.

Simulation-based methods utilise Computational Fluid Dynamics (CFD) and Design Environment for Low Amplitude Thermoacoustic Energy Conversion (DeltaEC) (Ilori et al., 2021) techniques to ascertain velocity profiles. On the other hand, experimental-based methods involve hot wire anemometry (HWA), laser Doppler anemometry (LDA), and particle image velocimetry (PIV). Despite the limited number of studies on the velocity profile of thermoacoustic systems, researchers such as X. Xiao et al. (2020), Mohd Saat et al. (2019), and Abd El-Rahman et al. (2017) have shown a preference for simulation-based methods, particularly CFD, over experimental methods. (Abd El-Rahman et al., 2017; Johari et al., 2018; Xiao et al., 2020).

This bias towards simulation data, rather than actual experimental data, may be attributed to the high setup costs associated with experimental rigs, especially for PIV and LDA setups. LDA systems, commonly used by scientists and professionals for a comprehensive understanding of fluid dynamics, were employed by Bailliet and colleagues to study flow measurements in a TAR resonator. (Bailliet et al., 2000). Their LDA measurements of pressure and velocity in the resonator were validated using analytical methods, with an error of less than 8%, indicating the agreement between experimental and analytical results.

However, it is essential to note that Zhang (2002) identified bias in LDA flow measurements (Zhang, 2002). He observed constant mean velocity across all measured data by comparing past raw data of TAR in 1D, 2D, and 3D with numerical calculations. This discrepancy highlighted the bias in LDA measurements due to turbulence influencing the results.

PIV is a technique that examines velocity vector measurements by tracking particle movement between two image frames captured by a camera during two light pulses (laser). In 2012, Blanc's colleagues conducted a study using time-resolved particle image velocimetry (TR-PIV) to analyse the vortex's impact on heat transfer. They discovered that the vortex occurred at a higher pressure than the acoustic pressure of 500 and 2500 Pa. This resulted in additional heating due to viscous dissipation in the gap of the stack, which caused a loss of efficiency. (Blanc-Benon et al., 2012).

Debesse and colleagues used simplified PIV measurements to study sound and streaming effects in a thermoacoustic system. By using different data analysis tools, they found that stronger sound waves caused irregular streaming (Debesse et al., 2014). In a study from 2020, Hireche's team looked at the flow in a thermoacoustic device using natural and computer-based PIV methods, looking at cases with and without a heat exchanger (Hireche et al., 2020). The results showed that natural flow had a significant impact on thermoacoustic effects.

Past research has shown that PIV gave valuable information about how things flow. In the Thermoacoustic Refrigeration (TAR) context, small changes in how the system works give researchers much to study, as seen in works like Zhang et al. (2013). This paper aims to add to what we already know by looking at how things flow and how fast they go in the resonator of a thermoacoustic system using PIV measurements.

EXPERIMENTAL PARTICLE IMAGE VELOCIMETRY (PIV) SETUP

The standing wave thermoacoustic device comprises a resonator, a stack, and an acoustic speaker. The resonator used was a transparent acrylic hollow tube, which allowed the laser of PIV to cross along. The resonator has a length of 100 cm, a diameter of 5 cm and a thickness of 1 cm

The stack, crafted from polylactic acid (PLA) material using a 3D printer, is depicted in **Figure 14.3** and **Figure 14.4**. The choice of a 3D printer is driven by its precision and time-saving advantages over alternative methods. The designed stack features a honeycomb structure with a diameter of 40 mm and a length of 60 mm. Each stack plate has a thickness of 0.5 mm, and the precise spacing between plates facilitates the movement of acoustic frequency and heat. This specific plate arrangement was chosen to study acoustic particle velocity using particle image velocimetry, showcasing the thoughtful consideration given to the experimental setup.

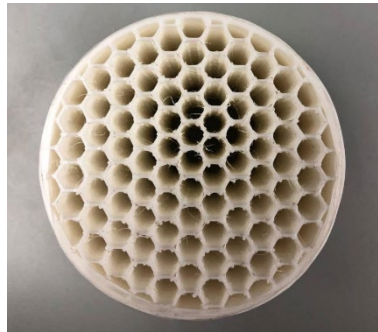


Figure 14.3: The 3-D printed honeycomb stack

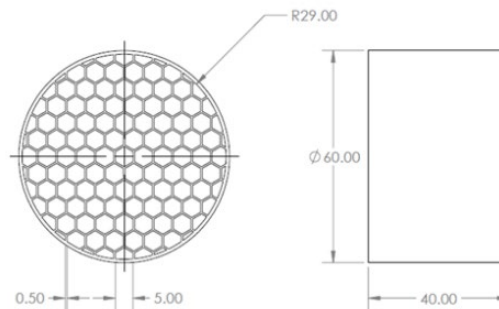


Figure 14.4: The schematic for the stack

Throughout the experiment, the frequency was maintained at 85.7 Hz. However, the location of the stack varies. The location of the stack is denoted as 'x'; the distance from the loudspeaker to the centre of the stack is 12 cm, 13 cm, 14 cm, 15 cm, and 16 cm.

The components necessary for the PIV setup are detailed in **Figure 14.5**. It illustrates schematic and actual elements. The laser beam is produced by a dual-resonator Nd: YAG laser with a wavelength of 532 nm, boasting a repetition rate of 15 Hz. This laser has a substantial energy output of 135 mJ with an energy stability of 2%, making it powerful enough to illuminate the seeding particles effectively. Positioned atop a transparent rectangular lance, the laser is strategically placed to illuminate the view window area, with the optical lens maintaining a distance of 40 cm from the upper wall of the resonator. The laser emits very short light pulses (approximately 5–7 ns), which effectively freeze the motion of the tracer particles during image capture. The time interval between the two consecutive laser pulses is adjusted according to the flow velocity to ensure accurate particle displacement measurements.

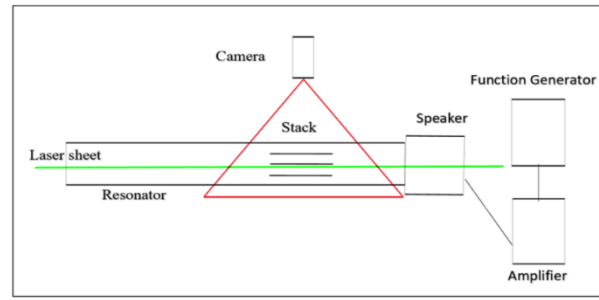


Figure 14.5: The arrangement of TAR and PIV from the top view

A single-camera system is employed for PIV, utilising an IMPERX ICL-B1620 camera featuring 1600 X 1200 pixels and a 14-bit resolution CCD sensor. The camera lens, a Nikon AF-S VR MICRO-NIKKOR 105 mm, is mounted on a multi-axis tripod with a 1:2.8 D lens.

In PIV measurements, the velocity of suspended particles in the flow is the "velocity indicator." Seeding particles, crucial for accurate flow observation, should be appropriately sized to scatter sufficient light for camera detection and be buoyant with a density close to the fluids. Three types of seeding particles are considered: glass beads, incense granules, and a fog of silicone oil. Among these, glass beads are chosen for easy bonding to the plexiglass wall, while a fog generator for testing generates a fog of silicone oil.

Before droplet ejection, the fog generator undergoes a 20-minute heating stage. The oil fog is then injected into the resonator before activating the loudspeaker, and additional fog is added if particle concentration decreases. The acoustic oscillation ensures homogeneity of seeding particles within the resonator, facilitating velocity particle measurement.

During measurement, the CCD camera captures 150 frames per 10 seconds at full resolution, while the maximum laser frequency is 15 Hz, slightly lower than the oscillation flow frequency. To address this, a phase-averaging method using phase-locking technology is employed. The velocity signal near the resonator's close end is transformed into a square wave signal with the same frequency.

This signal triggers the laser and camera to acquire images at the same phase of the cycles, resulting in instantaneous velocity fields for each phase that are then averaged to obtain a phase-averaged velocity field. The PIV data processing software Dynamic Studio v3.4 determines scalar maps through a few data processes like Image Masking. The study area is kept small to ensure no significant velocity gradient within the study area, following recommendations from past PIV research.

RESULTS AND DISCUSSION

Figure 14.6 until **Figure 14.10** display the different flow patterns inside the resonator tube caused by various stack locations, marked as 'x' (the distance from the loudspeaker to the centre of the stack), with the hollow part indicating the position of the stack within the resonator tube.

The PIV analysis of the flow patterns shows several notable findings. When the loudspeaker is turned on, the air velocity increases due to the influence of the acoustic sound wave in the resonator. As the sound wave enters the stack, there is a noticeable increase in air velocity at the entrance, causing vortex formation. This observation is consistent with an earlier study by Allafi and colleagues in 2021, which found that air passing back and forth past flat plates creates swirls of air at both ends of the plates. The swirls are most potent at the end of the plates, where the air changes direction after bouncing back from the end of the resonator.

The speed of the air between the plates in the stack remains the same as the air's speed before entering the stack. When the air exits the stack, its speed increases again as it flows through the narrow gap between the plates. Notably, the images indicate significant air swirls at the stack's exit. This finding is crucial and requires further investigation since airflow movement affects heat transfer between the plates and the fluid they work with. Additionally, these results suggest that the airflow may have enough wobbling to cause turbulence.

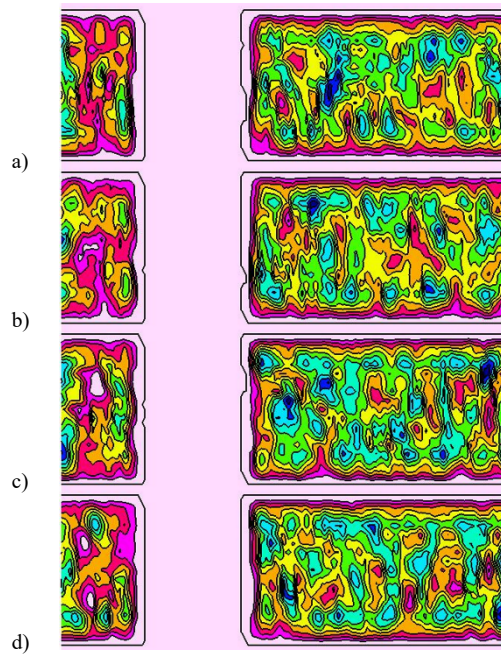


Figure 14.6: $x=12$ cm; a) at time stamp 0 s; b) at time stamp 2.667 s; c) at time stamp 5.33 s; d) at time stamp 8.00 s

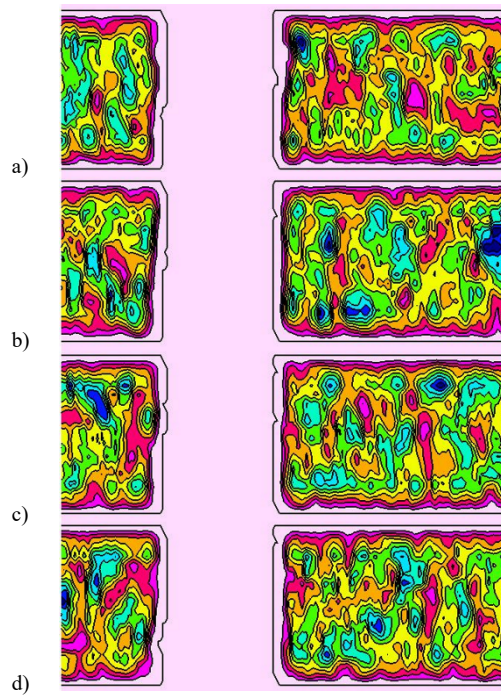


Figure 14.7: $x=13$ cm; a) at time stamp 0 s; b) at time stamp 2.667 s; c) at time stamp 5.33 s; d) at time stamp 8.00 s

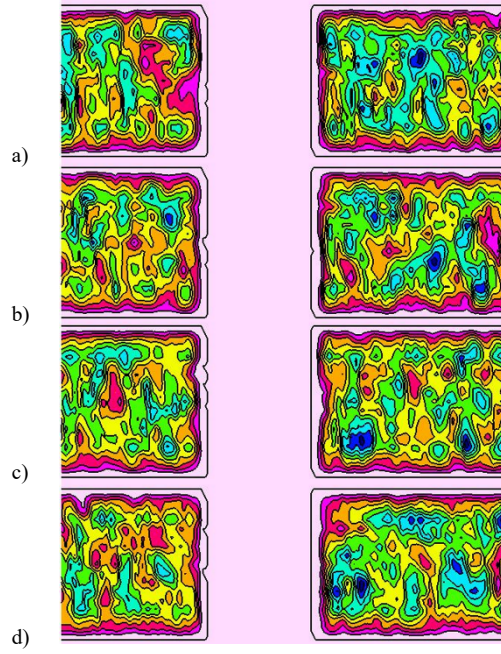


Figure 14.8: $x=14$ cm; a) at time stamp 0 s; b) at time stamp 2.667 s; c) at time stamp 5.33 s; d) at time stamp 8.00 s

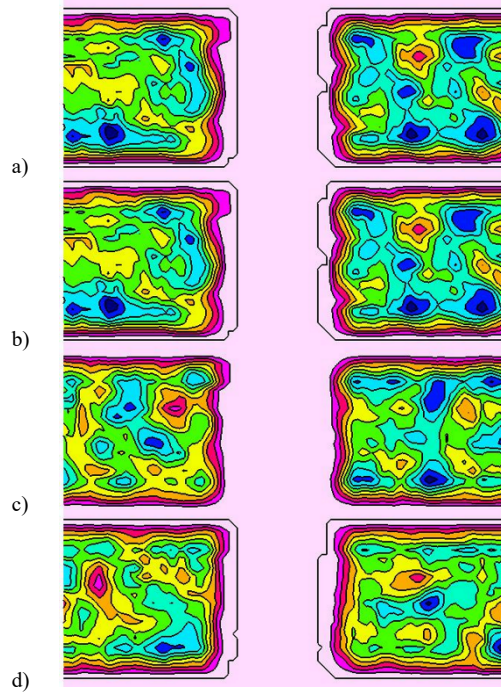


Figure 14.9: $x=15$ cm; a) at time stamp 0 s; b) at time stamp 2.667 s; c) at time stamp 5.33 s; d) at time stamp 8.00 s

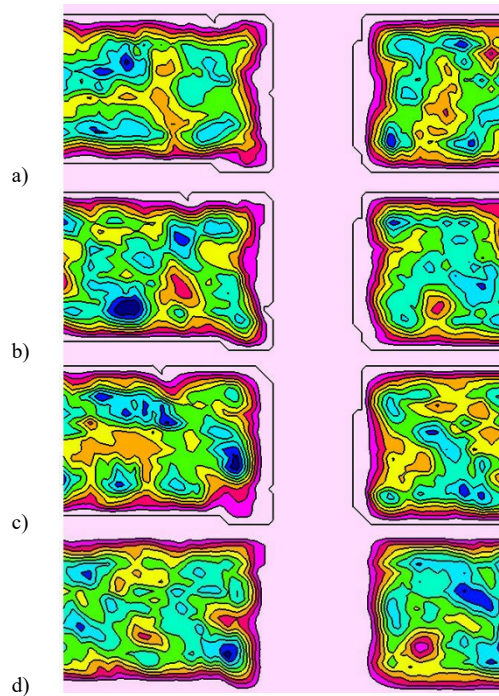


Figure 14.10: $x=16$ cm; a) at time stamp 0 s; b) at time stamp 2.667 s; c) at time stamp 5.33 s; d) at time stamp 8.00 s

CONCLUSION

This experiment aimed to study the flow pattern of oscillatory flow and how the stack affects it in a thermoacoustic refrigerator. The experiment revealed important information about the flow dynamics within the system. The flow in front of the stack was linear and harmonic, indicating a predictable and regular pattern.

After the stack region, the oscillating flow transforms and creates vortex flows. The acoustic flow separates from the stack on its two downstream sides, and vortices form as the boundary layer becomes detached and curls back on itself. Interestingly, vortex formation is also observed at the entrance of the stack, suggesting that the disturbance in flow from a larger space to a narrower space plays a role in this pattern.

The spacing of the stack is a critical factor in vortex formation at the entrance of the stack. The narrow spacing contributes to the disturbance in the flow, prompting the creation of vortices. Moreover, the velocity drops to a minimum in the middle of the stack, possibly due to the stack plates' structural support. The support structure acts as an obstruction, blocking the flow and resulting in a sudden decrease in velocity at that location. Understanding the flow patterns and their variations is crucial for optimising the design and performance of thermoacoustic refrigerators.

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