ENHANCED THE MECHANICAL PROPERTIES OF WELDING BUTT JOINT OF ALUMINUM ALLOY 6061 BY T6 HEAT TREATMENT PROCESS

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ABSTRACT: The effect of T6 heat treatment process parameters on the tensile properties of welding butt joint was investigated. T6 heat treatment parameters selected are temperature and time of solution heat treatment (SHT), temperature and time of ageing. Taguchi method and analysis of variance (ANOVA) are used to optimize the heat treatment parameters and to improve the percentage of responses. Aluminum alloy 6061 of dumbbell shape specimen was cut by wire EDM machine followed by T6 heat treatment process. Then the tensile test was conducted to observe the ultimate tensile strength and tensile modulus. From ANOVA, the most affected parameters for ultimate tensile strength and tensile modulus is the temperature of SHT. The value of ultimate tensile strength and tensile modulus obtained for the original welded sample without heat treatment are 89.343 MPa and 17.50 MPa respectively. After heat treatment, the ultimate tensile strength and tensile modulus is increased to 231.964 MPa and 28.57 MPa respectively. It is found that the percentage of ultimate tensile strength and tensile modulus improved up to 8.4 % and 5.09 % respectively. The refinement of grains microstructure after T6 heat treatment process was responsible for enhancement the mechanical properties of welded part.

KEYWORDS: *T6 Heat Treatment; Welding Butt Joint; Aluminum Alloy 6061*

1.0 INTRODUCTION

The competition among companies is quite competitive mainly in the manufacturing industries. This is due to endeavour in establishing the new aims to fulfill customers' demand and satisfaction where they need to identify the best resolution. All the way through the manufacturing revolution era, heat treatment is mostly applied to enhance the mechanical properties of the metals. Heat treatment is able to change the physical properties by monitoring the heating and cooling phases without the shape of the product has been interrupted. Gas Metal Arc Welding (GMAW) was performed in this project. GMAW produces an electrical arc among the workpiece and a continuously fed electrode that initiating them to soften and joint. Besides, the process of shielding gas feeds through the welding gun, it will protect welding area from pollutants in the air. Ramos-Jaime et al. [1] mentioned that the molten electrode is transmitted to the workpiece through the electric arc and assists as the weld bead. These days most productions use robotic welding tools for the coalescence process. In addition, the robotic welding method has more benefits than the conventional manual method, for instance the quality of weld is more consistent, the process speed was higher compared with manual, there was less waste and a reduced rate [2].

In this project, the heat treatment process chosen was T6 heat treatment process. The purpose of heat treating is to make metal stronger, harder and resistance to impact. In T6 heat treatment process as shown in Figure 1 [3], there are three consecutive phases in heat treatment of aluminum alloy which at first phases is solution heat treatment where it is the dissolution of soluble elements from alloy into solid solutioning (T_{sol}). Next phase is quenching where the metals go through the rapid cooling of metals from the temperature of SHT to a room temperature. Lastly, the last phase of heat treatment is artificial ageing or precipitation heat treatment at the required artificial ageing temperature (T_a).

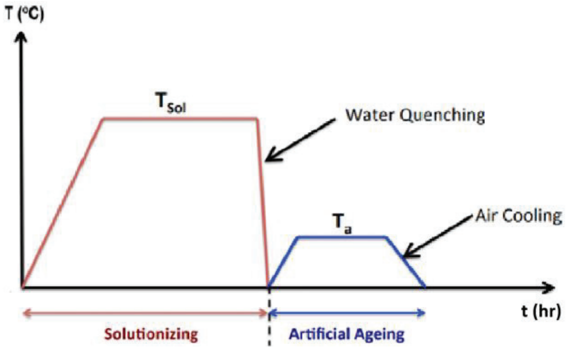

Figure 1: Phases of heat treatment process [3]

The parameters involved in the heat treatment process can influence the improvement of mechanical properties of welded part. Parameters of heat treatment involved are solution heat treatment and artificial ageing. According to Lombardi et al. [4], the first phases of heat treatment is solution heat treatment (SHT). Throughout this phase, the metal is heat treating at elevated temperature which certainly not reach the molten state. The effect of SHT is substantial and beneficial in order to enhance the mechanical properties of the welded part. The resolution of heat treatment is the dissolution of soluble elements from alloy into solid solution. To reach a virtually standardized solid solution, the process of soaking aluminum alloy at a suitably high temperature for moderately a long time. Kumar et al. [5] stated that if overheating in solution occurs, it may possibly damage the properties such as fracture toughness, tensile and ductility.

Further, artificial ageing has generally been heat treated at a specific temperature and time to enhance the mechanical properties. According to Smeadă and Stoicănescu [6] artificially aged by unconventional heat treatments contributes in improving the mechanical properties. Chand and Madhusudhan [7] stated that ageing increased the hardness of samples that were solution treated, and due to precipitation. Consequent drop in hardness can be attributed to overaging caused by coarsening of the precipitates. When the preferred amount of precipitates has formed the material is requenched to freeze the precipitation process at a suitable point, ever since overaging frequently leads to drops in properties.

However, in order to obtain better heat treatment process parameter setting, the implementation of design of experiment (DOE) is needed to remove the trial and error method that is time consuming and not cost effective. According to Barghash and Alkaabneh [8], DOE is a very useful tool to analyze complicated industrial design problems and to understand the process characteristics. Investigations on how parameter inputs affect the output can be made based on statistical principles in the DOE. Many researches have been carried out to optimize process parameters using Taguchi method in various applications. Taguchi method has been preferred by many researchers because this method reduced the number of experiments and cost saving [9-10]. Vempati et al. [11] optimized welding parameters using Taguchi method to improve the weld strength of the Ti 6al 4v weld joint. In addition, Singh et al. [12] have applied Taguchi method for investigation of heat treated weld joint Mild steel SAE1017 mechanical properties.

Therefore, this paper aims to investigate the influence of heat treatment parameters such as instance temperature of solution heat treatment (SHT), time of SHT, temperature of artificial ageing and time of artificial ageing on ultimate tensile strength and tensile modulus using Taguchi method.

2.0 METHODOLOGY

2.1 Experimental Method

KUKA welding machine has been used because of its exact positioning accuracy during the operation of welding. In this experiment, after the welding of the samples, the samples have undergone heat treatment process. After that the welded samples were cut using wire cut machine based on the ATSM E8/E8M standard. Finally, tensile test was conducted to determine its mechanical properties. Here, is the detail of the experimental method. After welding, the sample was continued with the heat treatment process using furnace. Further, the welded sample of aluminum alloy 6061 testing specimen that was cut by using wire cut Sodick VZ300L machine with the dimension was taken from ASTM E8/E8M. The ultimate tensile strength and tensile modulus were carried out using Universal Testing Machine Instron. The speed used to conduct the tensile test was 50 mm/min. Each testing was done by three repetitions.

Meanwhile, microstructure observation was performed using the size of cut about 6 mm x 20 mm x 30 mm for easy holding by hand during polishing. The optical microscope (Zeiss, Axioskop 2) is used with the 20-time magnification for microstructure observation. Before that, the sample is grinded by using 240, 320, 400, 600, 800 and 1200 grit sandpaper. After that, the sample was firstly polished by using 8 inch textpan with 6 μm diamat + dialube lapping lube. Then, secondly, the sample was polished by using 8 inch textpan with 3 μm diamat + dialube lapping lube. Thirdly, the sample was polished by using 8 inch micropad polishing pad with 0.3 μm nanopolish alumina + dialube lapping lube and lastly the sample was polished by using 8 inch micropad polishing pad with 0.05 μm nanopolish alumina. The surface of sample is then etched by using Keller's reagent for 15 seconds. The optimization of heat treatment parameters on mechanical properties for aluminum alloy used Taguchi method. Data are being analysed using Taguchi method to determine the most significant parameter to the output responses.

2.2 Heat Treatment Parameters

There are four most important parameters that have been identified which are temperature SHT, time SHT, temperature ageing and time ageing as shown in Table 1.

Table 1: Heat treatment parameters

Process Parameters	Units	Recommended Levels
Temperature SHT	^{o}C	500, 540, 580
Time SHT	hr	6, 8, 10
Temperature ageing	^{o}C	140, 160, 180
Time ageing	hr	2, 3, 4

3.0 RESULTS AND DISCUSSION

3.1 Ultimate Tensile Strength (UTS)

Table 2 shows the experimental result and S/N ratio of ultimate tensile strength. After the welded samples of aluminum Alloy 6061 were being treated by using T6 heat treatment process, the maximum value of UTS is increased up to 231.964 MPa at run number 7. In this experiment, the result of UTS without heat treatment was aslo measured. However, the value of UTS for welded sample without heat treatment shows lower than after heat treatment which is 89.343 MPa. This result similar with Sreeharan and Kannan [13] which reported that heat treatment process has enhanced the strengthen of welding area. In their research, they found that the enhancement of tensile strength due to the finer grains of microstructure that can be achieved by heat treatment process.

In Taguchi method, S/N ratio is used to represent a performance characteristic and the largest value of S/N ratio is required. The higher-the-better characteristic was selected for ultimate tensile strength as shown in Equation (1). The S/N ratio is the ratio of the mean (signal) to the standard deviation (noise). Where n is the number of experiment, yi is the value of response of ith experiment. As result, the run number 1 of S/N ratio was 42.7127.

$$\frac{S}{N} = -10\log\left(\frac{1}{n} \sum_{i=1}^{1} \frac{1}{yi^2}\right) \tag{1}$$

Table 2: Experimental result of ultimate tensile strength

Run	Temp. SHT (°C)	Time SHT (hr)	Temp. Ageing (°C)	Time Ageing (hr)	Avg. UTS (MPa)	S/N ratio
1	500	6	140	2	136.658	42.7127
2	500	8	160	3	182.452	45.2230
3	500	10	180	4	185.989	45.3897
4	540	6	160	4	197.161	45.8964
5	540	8	180	2	215.808	46.6814
6	540	10	140	3	209.137	46.4086
7	580	6	180	3	231.964	47.3084
8	580	8	140	4	226.096	47.0859
9	580	10	160	2	193.625	45.7392

Based on Table 2, the S/N ratio of each process parameter was generated to create S/N response diagram. The S/N response diagram was constructed as shown in Figure 2. The result shows that UTS increases with increasing of temperature of SHT and ageing with similar result reported by Ding et al. [14]. They found that the morphologies of the coarse alluminium alloy particles formed more grain refinement and homogeneous fine grain structure with the increased of the heat treatment temperature. Time of SHT optimum at the middle due to if not appropriate time selected, the properties of the part can damage [5].

Further, the optimization process was taken at the highest value of S/N ratio which the most level factor influences the response. As shown in the figure, the S/N ratio graph, the highest value for S/N ratio for temperature of SHT is 46.71 at the temperature of 580 °C at level 3. For the time of SHT, the S/N ratio value is 46.33 at time of 8 hours. The value of S/N ratio for temperature of ageing is 46.46 at temperature of 180 °C. For the time of ageing, the maximum value of S/N ratio is 46.31 at time of 3 hours. Based on Table 3, the greatest value of R-Sq (%) was the temperature of SHT which specify the value of 61.14 %. Next, followed by the time of ageing in rank 2, temperature of ageing in rank 3 and lastly time of SHT in rank 4. It can be concluded that the most significant factor which affecting the ultimate tensile strength were temperature of SHT, followed by time of ageing, temperature of ageing and time of SHT.

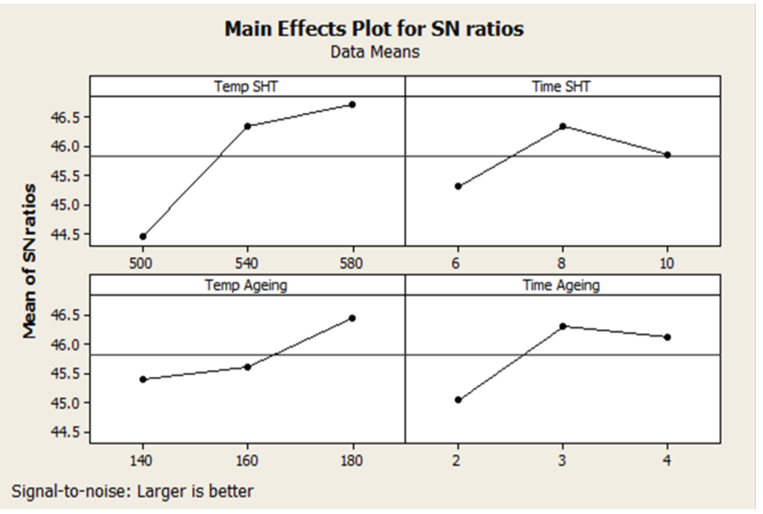

Figure 2: S/N ratio graph of ultimate tensile strength

Table 3. Analysis of variance (ANOVA) of ultimate tensile strength

Parameters	P value	R-Sq (%)	Rank
Temperature SHT	0.059	61.14	1
Time SHT	0.757	8.86	4
Temperature ageing	0.665	12.71	3
Time ageing	0.566	17.29	2

Afterward all the control factors of optimal levels are recognized, the last stage in Taguchi parameter design is the confirmation experiment. The highest optimum value which obtained from highest parameter as in Figure 2. The optimal parameter levels identified were temperature SHT 580 ^{o}C, time SHT 8 hours, temperature ageing 180 ^{o}C and time ageing 3 hours. Based on optimization level, it is found that the value of ultimate tensile strength increases to 251.488 MPa after the analysis. The ultimate strength is increased up to 8.4 % from the highest experimental result on run number 7 which is 231.964 MPa.

3.2 Tensile Modulus

Table 4 shows the experimental result and S/N ratio of tensile modulus. The maximum value of tensile modulus is increased up to 28.57 MPa at run number 7. In this experiment the value welded sample without heat treatment of tensile modulus is also measured which is 17.50 MPa. Ultimate tensile strength and tensile modulus without heat treatment show 89.343 MPa and 17.50 MPa as compared when increasing the heat treatment as 231.964 MPa and 28.57 MPa, respectively. This phenomenon due to heat during welding process resulted the premature failure of the welding area. However, after heat treatment process the grains return to their normal grain size and homogenous distribution of grains was formed [13,15].

Table 4: Experimental result of tensile modulus

Run	Temp. SHT (°C)	Time SHT (hr)	Temp. Ageing (°C)	Time Ageing (hr)	Avg. Tensile Modulus (MPa)	S/N ratio
1	500	6	140	2	12.50	21.9382
2	500	8	160	3	17.50	24.0824
3	500	10	180	4	20.00	26.0206
4	540	6	160	4	22.73	27.1320
5	540	8	180	2	25.00	27.9588
6	540	10	140	3	22.73	27.1320
7	580	6	180	3	28.57	29.1182
8	580	8	140	4	25.00	27.9588
9	580	10	160	2	25.00	27.9588

The higher-the-better characteristic was selected for tensile modulus for optimization process. S/N ratio of tensile modulus is calculated using higher-the-better quality characteristic using Equation (1). Based on Table 4, the S/N ratio of each process parameter was generated to create S/N response diagram. The S/N response diagram for tensile modulus was constructed as shown in Figure 3. From the figure, the value for the S/N ratio for temperature of SHT is 28.35 at a temperature of 580 °C. Next, for the time of SHT, the S/N ratio value is 27.04 at time of 10 hours. The value of S/N ratio for temperature of ageing is 27.70 at a temperature of 180 °C. For the time of ageing, the maximum value of the S/N ratio is 27.04 at time of 4 hours.

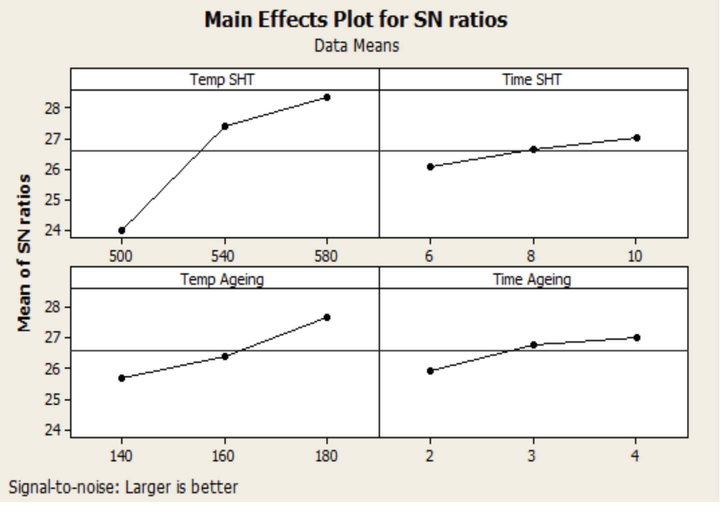

Figure 3: S/N ratio graph of tensile modulus

Table 5: Analysis of variance (ANOVA) of tensile modulus

Parameters	P value	R-Sq (%)	Rank
Temperature SHT	0.008	80.10	1
Time SHT	0.962	1.28	4
Temperature ageing	0.596	15.83	2
Time ageing	0.919	2.79	3

Based on Table 5, the greatest value of R-Sq (%) was the temperature of SHT which specify the value of 80.10 %. Next, followed by the temperature of ageing, time of ageing and time of SHT. It can be concluded that the most significant factor which affecting the tensile modulus were temperature of SHT, which P value below than 0.05.

After that all the control factors of optimal levels are recognized, the last stage in Taguchi parameter design is the confirmation experiment. The optimal parameter levels identified were temperature SHT 580 ^{o}C, time SHT 10 hours, temperature ageing 180 ^{o}C and time ageing 4 hours. Based on optimization level, it is found that the value of tensile modulus increases to 30.02 MPa after the analysis. The tensile modulus is increased up to 5.09 % from the highest experimental result on run number 7 which is 28.57 MPa. Result from the ultimate tensile strength and tensile modulus show that temperature SHT is the most significant parameter. This is because at first heating of SHT, aluminium alloys formed homogenous solid solution.

According to Lee and Mishra [16], SHT process was the first step in the process of hardening process, where alloys were heated at certain temperature and hold enough time until equal solid solution was formed which has formed course and large size of grains. Subsequently, rapid water quenched process remains the condition of grains. At this position the tensile and modulus strength very weak and brittle. Further, by ageing hardening process as a function of time the grains dislocation network reduce and eliminate which enhanced the mechanical properties of welding aluminium alloys.

3.3 Microstructure

The microstructure is used to observe the grain size of the material at weldment area and base metal by using an optical microscope. Microstructure affects the physical properties and behavior of the material. According to Obayi et al. [17], the mechanical properties of material enhanced significantly when the grain size is decreased. Based on Hall-Petch relationship, the ultimate tensile strength and tensile modulus were increasing with decreasing of recrystallized grain size. Figure 4 shows specimen image in a larger view under the optical microscope.

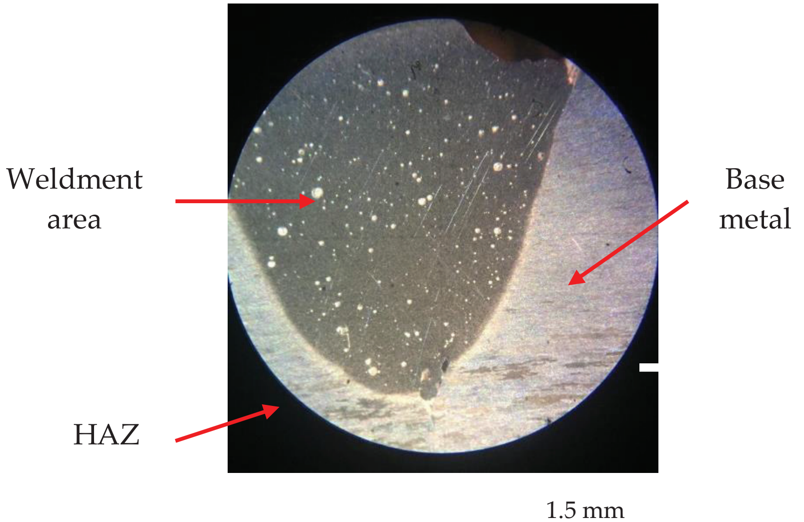

Figure 4: Specimen image under the optical microscope

As shown in Figures 5 (a) and 5 (b), the grain size at the base metal is larger than the grain size at weldment area. It can be concluded that in the weldment area, the strength and hardness are stronger as compared to the base metal [18]. Grains show a propensity of having uneven grain size in the heat-affected zone (HAZ) as shown in Figure 6 due to high heat input to the material. HAZ is upraised to an adequately high temperature to produce a coarse grain size. At high temperature region, the coarse grain size is not only more hardenable but also less ductile.

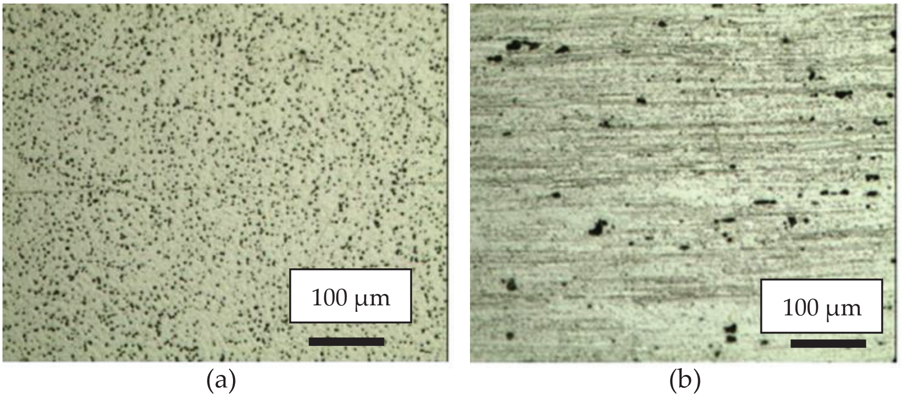

Figure 5: Grain size at (a) base metal and (b) weldment area

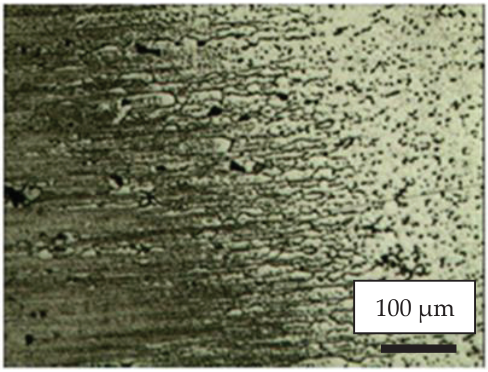

Figure 6: Grain size at heat-affected zone (HAZ)

4.0 CONCLUSION

According to the results obtained from the stress strain graph, the parameters for the sample number 7 was the best parameter to be used because it can increase the ultimate tensile strength of the welded sample. Further, by using Taguchi method optimization process, the ultimate tensile strength was increased to 8.4 %. Besides that, the tensile modulus of welded sample was increased to 5.09 % after optimization. Further, the most significance factor affected the ultimate tensile strength and tensile modulus is the temperature of SHT. It can be concluded that temperature of SHT is the main factor for the T6 heat treatment process to enhance the ultimate tensile strength and tensile modulus of aluminum alloys A6061. HAZ microstructure shows fine grain size at weldment area as compared to the base metal. The objectives of this study was achieved which the mechanical properties of butt joint welded can be enhanced by T6 heat treatment process.

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REFERENCES

[1] D. Ramos-Jaime, I. López-Juárez and P. Perez, "Effect of process parameters on robotic GMAW bead area estimation", *Procedia Technology*, vol. 7, pp. 398-405, 2013.

[2] S. Yacob, M.A.M. Ali, Q. Ahsan, N. Ariffin, R. Ali, A. Arshad, M.I.A. Wahab, S.A. Ismail, N.M. Roji, W.B.W. Din and M.H. Zakaria, "The effect of welding parameters on surface quality of AA6351 aluminum alloy", *IOP Conference Series Materials Science and Engineering*, vol. 100, no. 1, pp. 1-5, 2015.

[3] I.A.B. Magno, F.V.A.D. Souza, A.D.S. Barros, M.O. Costa, J.M. Nascimento, T.A.P.D.S. Costa and O.F.L.D. Rocha, "Effect of the T6 heat treatment on microhardness of a directionally solidified aluminum-based 319 alloy", *Materials Research*, vol. 20, no. 2, pp. 662-666, 2017.

[4] A. Lombardi, C. Ravindran and R. MacKay, "Optimization of the solution heat treatment process to improve mechanical properties of 319 Al alloy engine blocks using the billet casting method", *Materials Science and Engineering: A*, vol. 633, pp. 125-135, 2015.

[5] N. Kumar, S. Goel, R. Jayaganthan and H.G. Brokmeier, "Effect of solution treatment on mechanical and corrosion behaviors of 6082-T6 Al alloy", *Metallography, Microstructure, and Analysis*, vol. 4, no. 5, pp. 411-422, 2015.

[6] M. Smeadă and M. Stoicănescu, "Experimental studies on improving the mechanical properties of aluminum alloys", *Review of the Air Force Academy*, vol. 1, no. 23, pp. 45-48, 2013.

[7] S. Chand and D. Madhusudhan, "Influence of high temperature solution treatment on aging characteristics of Al-4Cu-6Si casting alloy", *International Journal of Engineering Technology Science and Research*, vol. 3, no. 1, pp. 12-16, 2016.

[8] M.A. Barghash and F.A. Alkaabneh, "Shrinkage and warpage detailed analysis and optimization for the injection molding process using multistage experimental design", *Quality Engineering*, vol. 26, no. 3, pp. 319-334, 2014.

[9] M.A. Md Ali, N. Idayu, M.S. Abd Aziz, M. Hadzley and Sivaraos, "Optimisation of process parameters in linear runner family injection mold using moldflow simulation software", *ARPN Journal of Engineering and Applied Science*, vol. 11, no. 4, pp. 2475-2482, 2016.

[10] G. Zheng, W. Guo, Q. Wang and X. Guo, "Influence of processing parameters on warpage according to the Taguchi experiment", *Journal of Mechanical Science and Technology*, vol. 29, no. 10, pp. 4153-4158, 2015.

[11] S.R. Vempati, K.B. Raju and K.V. Subbaiah, "Optimization of welding parameters of Ti 6Al 4V cruciform shape weld joint to improve weld strength based on Taguchi method", *Materials Today: Proceedings*, vol. 5, no. 2, pp. 4948-4957, 2018.

[12] R. Singh, P. Bhingole and S. Avikal, "Gray based Taguchi optimization for heat treated welded joint", *Materials Today: Proceedings*, vol. 5, no. 9, pp. 19156-19165, 2018.

[13] B.N. Sreeharan and T. Kannan, "Investigation on the microstructure and mechanical behaviour of post-weld heat treated AA6351 aluminium weldments", *Materials Research Express*, vol. 6, no. 4, pp. 1-12, 2019.

[14] X.F. Ding, S. Jing, Y. Jia, W.D. Zhang and L.C. Wang, "Influences of aging temperature and time on microstructure and mechanical properties of 6005A aluminum alloy extrusions", *Transactions of Nonferrous Metals Society of China*, vol. 22, pp. s14-s20, 2012.

[15] M.R.M. Kamal, N.F. Bazilah, A. Luhat, M.H. Idris, M.S. Salleh and W.F.F.W. Ali, "Effect of semi-solid forming temperature and heat treatment on mechanical properties of Mg-Al-Zn Alloy (AZ91D) for automotive application", in Mechanical Engineering Research Day, Melaka, 2019, pp. 28-29.

[16] E. Lee and B. Mishra, "Effect of cooling rate on the mechanical properties of AA365 aluminum alloy heat-treated under T4, T5, and T6 conditions", *International Journal of Metalcasting*, vol. 12, no. 3, pp. 449-456, 2018.

[17] C.S. Obayi, R. Tolouei, A. Mostavan, C. Paternoster, S. Turgeon, B.A. Okorie and D.C.S. Mantovani, "Effect of grain sizes on mechanical properties and biodegradation behavior of pure iron for cardiovascular stent application", *BioMatter*, vol. 6, no. 1, pp. 1-9, 2016.

[18] G. Arun, M. Harsha and A.B. Naik, "Experimental analysis of microstructure and mechanical properties of mig welded AA 7075-T6 of 10mm thickness", *International Research Journal of Engineering and Technology*, vol. 3, no. 10, pp. 768-773, 2016.