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Optimization of Iron Oxide (Fe_2O_3) Addition Parameters on the Physical Properties of Al-Si Alloys as an Advanced Material Innovation

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ABSTRACT

Aluminum-silicon alloys are widely used in the industrial world, one of which is because they have high wear resistance. The aim of this research is to determine the physical and mechanical properties of the Al-Si alloy after strengthening by mixing reinforcing materials. The research method uses Taguchi optimization and analysis of the physical properties of the Al-Si alloy test results. The results showed that the highest hardness value was obtained in the 7th experiment, namely with a rotation variation of 2000 rpm, temperature of 600^{0}C, and holding time of 60 seconds. This result is in line with the results of the tensile strength test, where the highest tensile strength was also obtained in the 7th experiment. This result is supported by the results of other researchers, which show that the higher the rotation in the casting results in higher hardness. The results of the microphotographs show that all alloy materials have an even distribution of grains, the grain size appears small, and the dendrites in the raw Al-Si alloy appear small compared to other materials. The macro photo results show that all alloy materials have fractures that appear brittle, as evidenced by the fact that these fractures provide light reflection.

Keywords: Al-Si, Phiysical Properties, Taguchi.

1. Introduction

Iron oxide (Fe_2O_3) or iron oxide is also known as iron ore (alpha form) or maghemite (gamma form) in mineral form. Alpha has several electrical conductor properties, is hard, and has a high specific gravity and can be applied in the foundry industry. Maghemite has the property of attracting certain objects, it has poles, different poles will attract each other and the same poles will repel each other and can be used to attract metals such as steel and iron.

In addition, nanometer-sized iron oxide (Fe_2O_3) has been widely used in various fields including pigments (dyeing agents), catalysts, as well as ceramic materials and magnetic recording [1]. In which, during the past two decades, much attention has been paid to the preparation of Fe_2O_3 with various sizes, morphologies and crystal phases. In the industrial field, Fe_2O_3 has potential applications in catalytic reactions in electronic devices such as semiconductors, paint formulations, and rechargeable lithium batteries. Aluminum-silicon alloys have good castability and weldability, good thermal conductivity, high temperature strength and excellent corrosion resistance. Therefore, these alloys are very suitable for applications in aerospace structures, automotive industries, and military equipment applications [2][3]. Al-Si alloys are the most useful of all common casting alloys in the manufacture of pistons for automotive engines. Depending on the concentration of Si in weight percentage, the Al-Si alloy system is divided into three main categories namely hypoeutectic (<12 wt% Si), eutectic (12-13 wt% Si), and hypereutectic (14-25 wt% Si) [4]. The melting points of Al and Si are 660.45°C and 1414°C respectively, while the eutectic reaction occurs at 12.6 wt% Si and 577 ± 1°C. The maximum solubility of Si in Al occurs at a eutectic temperature of 1.65 wt%. At least until the late 1950s, the eutectic was believed to be at 12.6 wt% Si. [5]. Both Fe_2O_3 and Al-Si alloys havehave crucial roles in various industrial applications, with Fe2O3 being widely used in catalysts and pigments, and Al-Si alloys serving as key materials in the automotive and aerospace industries.

Understanding the properties and applications of these materials is essential for advancing technological innovations

2. Methodology of Research

The research method used in this study is a quantitative research type with descriptive analysis. This research is an experimental research that is preceded by an optimization process using the Taguchi Method [6]. The optimization process uses the help of Minitab 16 software. Continued with the analysis of physical properties using a microscope test tool. It will show the microstructure of cast product about the grain size and this shape.

Table 1. Taguchi Design L9 (3^3)

	Rotation (rpm)	Temperature (℃)	Holding time (s)
1	1000	600	30
2	1000	700	45
3	1000	800	60
4	1500	600	45
5	1500	700	60
6	1500	800	30
7	2000	600	60
8	2000	700	30
9	2000	800	45

Table 1 above is a table resulting from Taguchi optimization design with casting rotation parameters (rpm), casting temperature (℃) and stir casting holding time (s). Each parameter consists of 3 levels, namely for casting rotation parameters (1000, 1500, and 2000 rpm), casting temperature (600, 700, 800 ℃), and for stir casting holding time (30, 45, and 60 seconds). Taguchi design consisting of 3 parameters and each parameter consisting of 3 levels (L9) produces 9 different experiments. According to Taguchi [7], These 9 experiments represent various possible variations and are therefore considered to be able to show the most efficient conditions in an experiment.

3. Result and Discussion

The table above is a table that presents the results of testing the mechanical strength of cast products. Cast products are Al-Si alloys produced from used pistons. Cast products are tested for hardness and tensile strength. In theory, the hardness value is directly proportional to the tensile strength of a material. This means that the harder a material is, the higher its tensile strength will be [8]. The table above shows that the highest hardness value was obtained in the 7th experiment, namely with a rotation variation of 2000 rpm, a temperature of 600 ℃, and a holding time of 60 seconds. This result is in line with the results of the tensile strength test, where the highest tensile strength was also obtained in the 7th experiment. This result is supported by the results of other researchers, which show that the higher the rotation in casting produces higher hardness [9]. This result is also supported by the results of Taguchi analysis on the S/N Ratio with the smaller is better characteristic, which is shown in Figure 1.

Table 2. Tensile Strength Test Results

No	Rotation (rpm)	Temperature (℃)	Holding time (s)	Hardness value (HV)	Tensile Strength (kg/mm^2)
1	1000	600	30	100.00	10.53
2	1000	700	45	101.17	11.42
3	1000	800	60	105.20	12.61
4	1500	600	45	111.00	11.73
5	1500	700	60	109.15	10.13
6	1500	800	30	113.00	10.88
7	2000	600	60	134,83	19.60
8	2000	700	30	128.32	17.86
9	2000	800	45	131.14	18.87

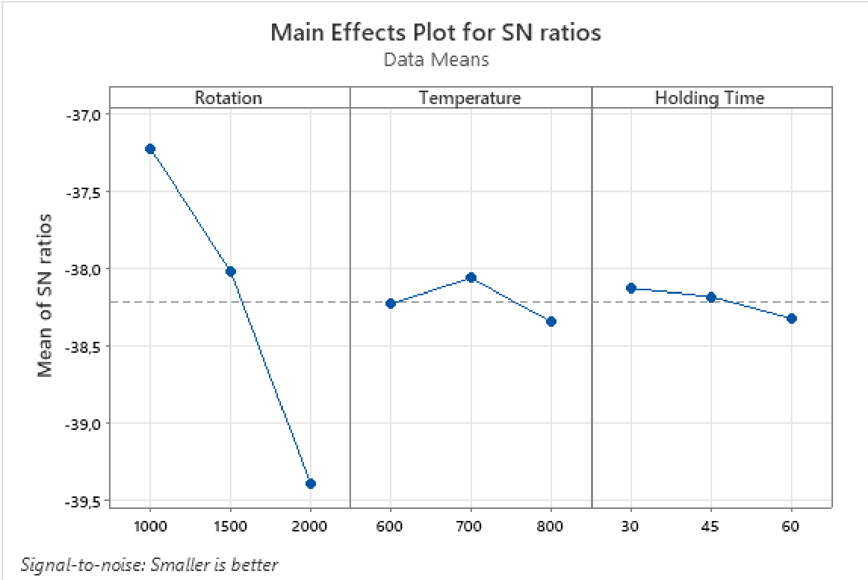

Figure 1. Taguchi Analysis Result

The results of Taguchi analysis on the S/N Ratio with the characteristics of smaller is better shown in Figure 1 can be interpreted that the most optimum parameters to obtain the highest hardness and tensile strength values are at a low level. So according to Figure 1, it can be concluded that the parameters that have the most influence on increasing the hardness and tensile strength of the Al-Si alloy are the casting machine rotation at rank 1, then the casting temperature at rank 2, and the holding time at rank 3. The results of Taguchi analysis on the S/N Ratio are integrated with the experimental results, it can be seen that the optimum stir casting parameters to obtain the most optimum mechanical properties of the Al-Si alloy are at 2000 rpm, 800℃ casting temperature, and 60 seconds holding time.

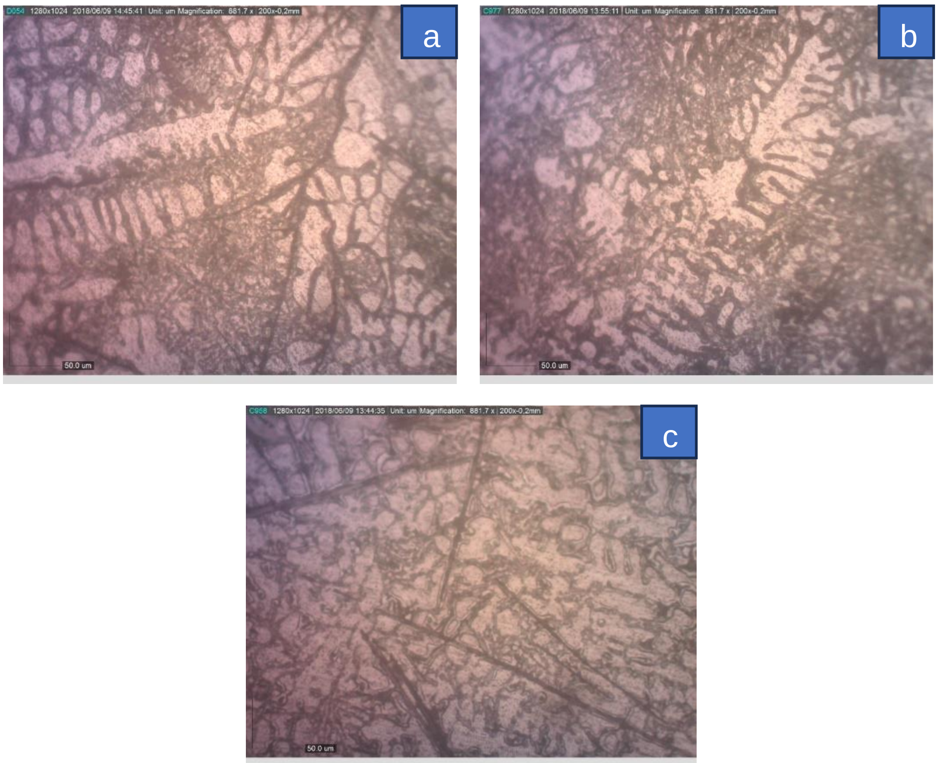

Figure 4. Al-Si Micro Photo Temperature 800℃

The microstructure of Al-Si alloys typically consists of a combination of primary aluminum dendrites, eutectic silicon and other possible phases like intermetallic compounds.. In Figure 2 Al-Si grain distribution appears even, grain size appears small, and dendrites appear small compared to other materials. Figure 3 Al-Si has a grain distribution that appears even, grain size appears small, while dendrites appear larger compared to raw Al-Si. Figure 4 has a grain distribution that appears more uneven and grain size is getting larger, while dendrites appear larger compared to Figure 2 and Figure 3. In Figure 2 above, it is known that the dendrites of Al-Si 600℃ material

appear smaller than other materials because the cooling and solidification process appears more perfect and faster. In the cooling and solidification process, the intermetallic phase is formed before the dendrite network formation process and grows freely in the liquid. If the dendrite network in the Al-Si alloy is getting bigger, it is caused by a slower cooling and solidification rate, which increases the risk of forming a large particle network because the time available for growth will increase. [10][11][12][13][14][15]. The microstructure of Al-Si in figures 2 – 4 shows the primary Si phase, Si phase and α phase - Al. In Figure 2-4, you can see that the grain size is getting finer, so the hardness and tensile strength are increasing. Beside this there are porosity defects in the Al-Si alloy caused by the presence of substances trapped at that point so that the cooling and solidification processes appear imperfect

Figure 5. Macro Photo of Al-Si Fracture Temperature 600℃

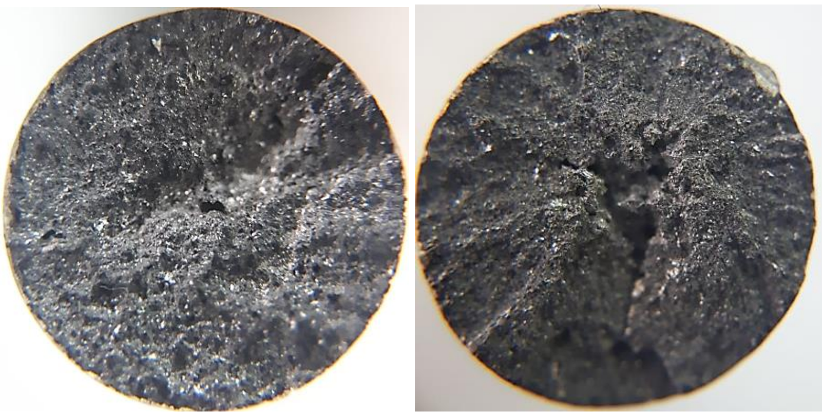

Figure 6. Macro Photo of Al-Si Fracture at Temperature 700℃

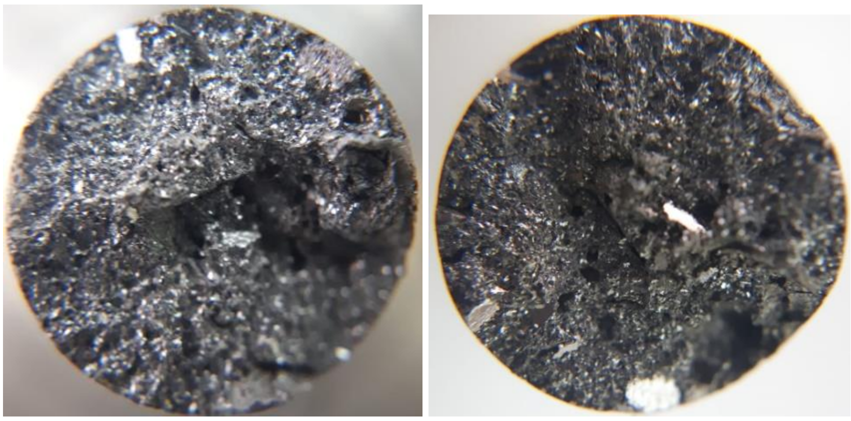

Figure 7. Macro Photo of Al-Si Fracture Temperature 800℃

In Figure 5, the material appears to be fractured ductile, this is seen to have undergone deformation or changes in shape caused by the absorption of large energy. The fracture surface also appears fibrous and the surface is uneven due to the shear stress that occurs in the Al-Si alloy. In Figure 6, the fracture material appears brittle, this is evident from the fracture surface that does not appear to have deformation and the fracture surface appears to have porosity defects caused by substances trapped at that point so that the cooling and solidification process appears imperfect. When the alloy appears to have porosity defects, the point where the porosity defects occur will become the center of stress so that the alloy cannot achieve maximum strength. In Figure 7, the fracture material appears brittle, the fracture surface provides light reflectivity, the surface appears flat, and the fracture surface appears to have porosity defects caused by substances trapped at that point so that the cooling and solidification process appears imperfect. Brittle fractures occur because the alloy cannot accept loads exceeding its strength. Ductile fracture can also occur because the alloy experiences elasticity first and then the alloy will break, while brittle fracture experiences plasticity so that the alloy is only able to withstand the maximum load that can be received by the alloy [16][17][18][19].

4. Conclusion

The results of Taguchi's analysis on the S/N Ratio, microstructure and macrostructure are integrated with the experimental results :

1. The optimum stir casting parameters to obtain the most optimum mechanical properties of the Al-Si alloy are at 2000 rpm, 800℃ casting temperature, and 60 seconds holding time.
2. The microstructure show that all alloy materials consists of a combination of primary aluminum dendrites and eutectic silicon. Grain size is smaller at the lower tempereature
3. The macrophoto show that the fracture appears ductile at the lower temperature, this can be seen from the occurrence of deformation.

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