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FATIGUE CRACK GROWTH RATE OF MOTORCYCLE WHEEL FABRICATED BY CENTRIFUGAL CASTING

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The aim of this study is to investigate the effects of the rotation speed of casting and T6 heat treatment on the fatigue crack growth rate of a motorcycle wheel manufactured using centrifugal casting. The density, porosity, tensile properties, and microstructure were examined in the evaluation of the fatigue crack growth rate of the aluminum scrap. The results showed that applying increased rotation speed is effective in increasing the alloy's tensile stress and material density, as well in reducing porosity and fatigue propagation rate. T6 heat treatment also increases the aluminum's tensile properties and reduces the fatigue crack growth rate. Recycled aluminum alloys can be improved by increasing the rotation speed of centrifugal casting and following it with T6 heat treatment in the production of a cast motorcycle wheel.

Key word: aluminum scrap, centrifugal casting, wheel, T6 heat treatment, fatigue

INTRODUCTION

Aluminum is a metal alloy that can be recycled into various components, such as automotive, motorcycle, and bicycle parts. The fabrication of vehicle wheels using metal forming with AM60B alloy has been previously studied [1]. Centrifugal casting has been intensively studied as a method to manufacture numerous products [2-3]. This technique improves products' microstructure and mechanical properties when compared to products fabricated by gravity permanent mold casting [4]. Products such as aluminum alloy motorcycle wheels have been manufactured by centrifugal casting [5].

T6 heat treatment is one technique used to improve alloys' strength and fatigue life [6-7].

The strain-controlled low cycle fatigue behavior of Mg–Y–Nd–Zr cast-alloy, and its improvement with T6 heat treatment, was studied [6]. The low cycle fatigue properties of A356 aluminum cast alloy after heat treatment were investigated [8]. The T6 heat treatment was optimized to enhance the fatigue properties of low-pressure die-cast A356 alloy. A T6 treatment and an aging temperature improved the number of cycles to failure for A356 alloy [9-12]. Other treatments, such as a shot peening process [13], physical vapor deposition (PVD) process [14], and new retrogression and re-aging (RRA) [15] also have the potential to reduce the crack growth threshold of aluminum alloys. Metal defects in the form of cracks during metal formation such as hot tearing are one of the causes of crack initiation and can influence to fatigue strength [16].

The aims of this experiment were to evaluate the characteristics of fatigue crack growth rate of a recycled aluminum alloy by increasing the rotation speed during the centrifugal casting process and applying T6 heat treatment.

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EXPERIMENTAL PROCEDURES

In this experiment, the casting process was begun by heating a metal mold to 250 ^{o}C. The molten alloy was stirred at temperatures of 730-750 ^{o}C for 5 min. After being held at 750 ^{o}C, the molten alloy was poured into a rotation mold until it fully solidified. The rotation speed was kept constant while the melt was poured into the rotation mold. The variants of the speed of rotation were 6,7 8,3 10 and 11,7 rotation per second (rps). Table 1 presents the chemical composition of the aluminum scrap alloy that was used to produce a motorcycle wheel by centrifugal casting. An electrical motor rotated the metal mold at controlled rotation speeds.

Table 1 **Chemical composition / *wt.*%**

Si	Fe	Cu	Mg	Zn	Ti
6,95	<0,1474	0,03	0,2683	0,0326	0,1329

The tensile, impact and fatigue test specimens were machined from the rim outer of the wheel in consideration of the fact that those areas will receive more load when it is used. The tensile and fatigue specimens adhered to the standards of ASTM-E8M and ASTM-E647 respectively.

The heat treatment can be defined as a combination of heating and cooling processing of metal alloys in a solidstate for a certain amount of time and with the intent to obtain specific properties. The solution heat treatment in this experiment consisted of heating the sample in an electrical furnace to reach a temperature at 535 °C for 4 hours and then fast quenching it with room-temperature water. This aims to prevent the diffusion of the structure and to ensure that the structure of the material is still in phase α. Subsequently, the specimen was reheated to 150 °C, then held at 150 °C for 2 hours. The sample was then placed into the furnace to release heatuntil reaching the room temperature. These steps are called an aging process.

RESULTS AND DISCUSSION

Figure 1a shows the density of aluminum scrap. The data shows similarity between the non-treated and treated specimens. The density was affected by changes in rotation speed. Density decreased from a rotation speed of 6,7 to a speed of 8,3 rps, then significantly increased for rotation speeds of 10 and 11,7 *rps*. The percentages of porosity represented by cast-aluminum scrap can be seen in Figure 1b. The highest rotation speed reduced the percentages of porosity, with 2,7 to 2,12 / % for products without heat treatment and 2,71 – 2,12 / % for the T6 heat treated product.

Figure 2 shows that the microstructure changed form in the sample subjected to T6 heat treatment. The Si size became smaller (intermittent) and was distributed at the grain boundaries, with precipitates evenly distributed in the aluminum matrix. This was caused by the T6 solution heat treatment process, followed by artificial aging. At this step, the material was heated to 535 °C for 4 hours and then immersed in water for rapid cooling (fast quench), so that the aluminum structure formed as a Supersaturated Solid Solution (SSSS). After that, the process continued with artificial aging and heating on the electrical furnace at 150 °C for 3 hours, which increased the SSSS hardness. The purpose of the precipitates is to prevent dislocation, which will improve the mechanical properties of the material.

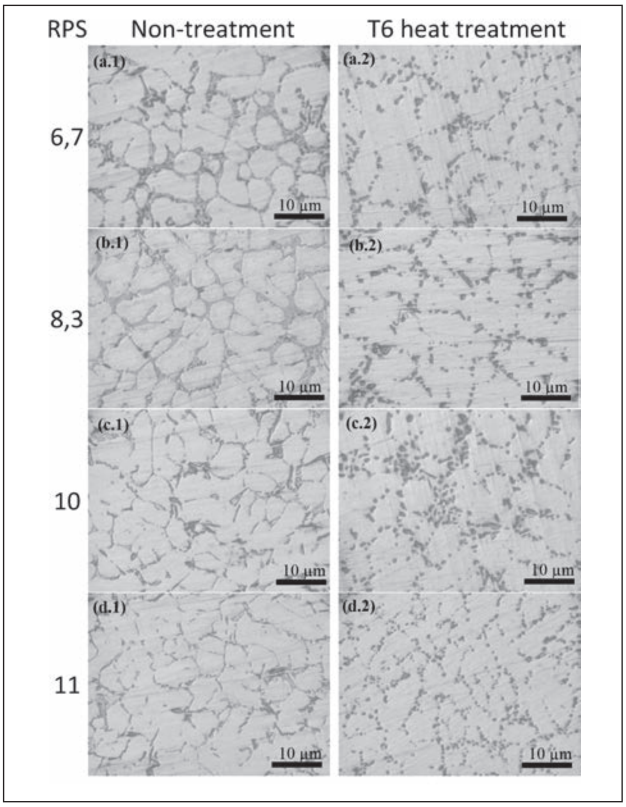

Figure 2 Microstructure with different speed rotation

Figure 3 Scanning Electron Microscopy (SEM) shows the striations on the fracture surface as a result of the fatigue crack growth, indicated by the arrows. The irregular curvature showed that the area was formed by ductile fracture, whereas the static fracture area (local failure) showed a brittle fracture. Overall, the fracture mechanism was a brittle fracture (cleavage fracture).

Figure 4 shows that the difference in speeds during centrifugal casting affects the tensile strength of cast aluminum scrap alloys. The experimental data shows that tensile strength increased slightly when rotation speed increased, while T6 heat treatment significantly

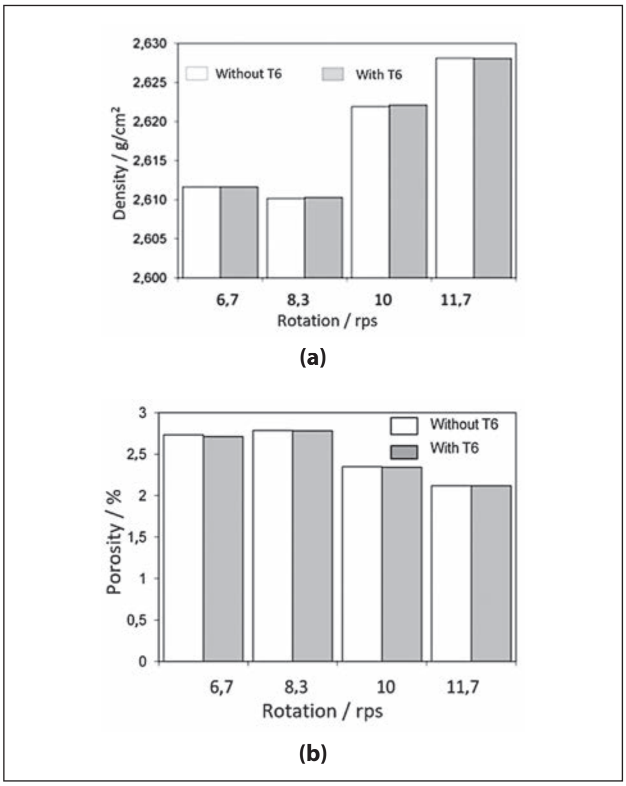

Figure 1 (a) density and (b) porosity

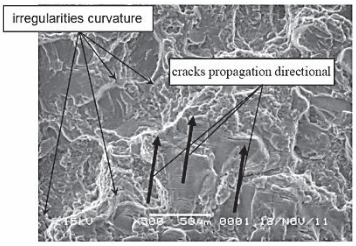

Figure 3 SEM image of fracture fatigue sample

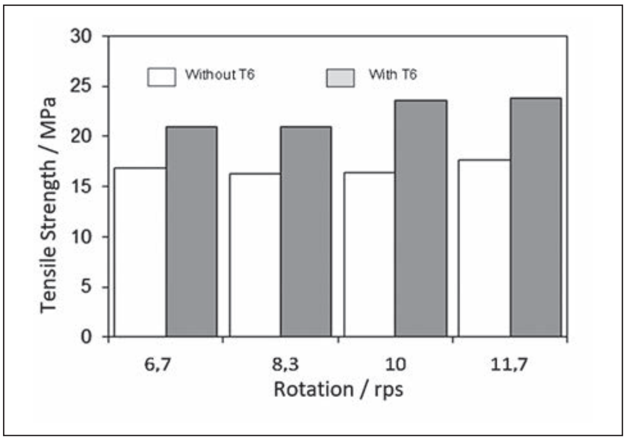

Figure 4 Tensile properties

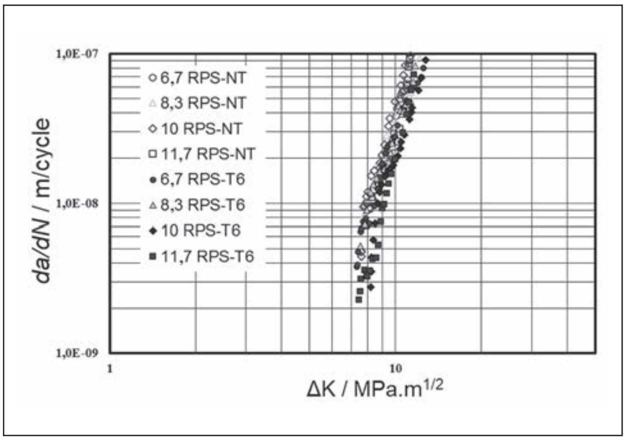

Figure 6 The fatigue crack growth rate.

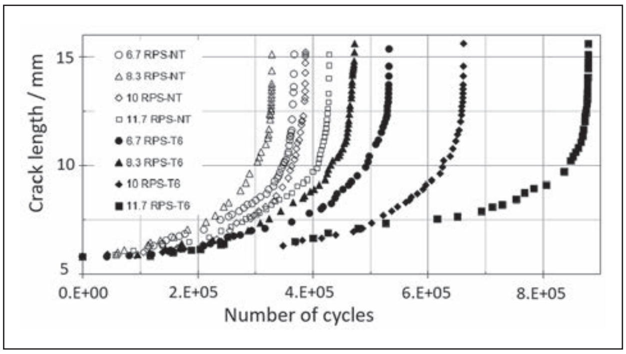

Figure 5 Fatigue crack length.

improved the alloy's tensile strength. The increase in tensile strength caused precipitates, thus inhibiting the occurrence of dislocation. A greater strength is needed to deform a dislocation on these samples, and the tensile strength becomes higher when T6 heat treatment is applied to the aluminum scrap alloy.

Figure 5 shows the crack length increments compared with the number of cycles with and without heat treatment at various rotation speeds. Samples without heat treatment at a rotation speed of 11,7 *rps* (11,7RPS-NT) had the highest number of cycles, about 428 200 cycles. Whereas, with a rotation speed of 8,3 *rps* (8,3RPS-NT), the sample had a low number of cycles (329 092 cycles). A sample cast at a rotation speed of 11,7 *rps* had slightly more rotations than a sample cast at a speed of 8,3 rps.This was due to its better mechanical properties compared to the 8,3 *rps* sample. However, the fatigue crack propagation in the 8,3 *rps* sample had a low rate.

The T6 heat treatment process significantly increased the number of fatigue cycles of aluminum scrap. At a rotation speed at 6,7 *rps* (6,7RPS-T6), the number of cycles grew from 369 010 to 532 808 cycles. At a rotation speed of 8,3 *rps* (8,3RPS-T6), the cycles rose from 329 092 to 472 960 cycles, and with rotation at 10 *rps* (10RPS-T6), the cycles increased from 387 580 to 662 213 cycles. The greatest improvement in the number of fatigue cycles was seen at a rotation speed of 11,7 *rps* (11,7RPS-T6), with an increase from 428 200 to 878 650 cycles. The conclusion can be drawn that increased rotation speed during centrifugal castingcan improve the number of fatigue cycles. Moreover, the fatigue cyclescan beimproved further by a T6 heat treatment process.

In the case of T6-untreated specimens, Figure 6 shows that a rotation speed of 11,7 rps (11,7RPS-NT) causes a lower rate of fatigue crack propagation than (6,7RPS-NT), represented by$da/dN = 5x10^{-12}(\Delta K)^{3,671}$, while the highest rate of fatigue crack propagation occurred at 6,7 *rps* (6,7RPS-NT), represented by $da/dN = 3x10^{-12}(\Delta K)^{4,166}$. This could be due to the uneven distribution of porosity in the area of crack propagation. The scrap's material factors were also influenced by the rate of crack propagation because of re-melting, in which the aluminum scrap alloy underwent a particular treatment, such as chemical and physical treatment, to fulfill a specific function. The result is that these treatments can affect the mechanical and physical properties of fatigue crack growth. The differences in the fatigue crack growth rate at rotation speeds of 6,7 8,3 and 10 *rps*were not very large, but at 11,7 *rps* a significant difference was seen. Therefore, the highest rotation speed during centrifugal casting reduced the crack growth rate of scrap aluminum alloy. The values of the fatigue propagation rate after T6 heat treatment can be seen in Figure 6. The lowest value is $da/dN = 4x10^{-12}(\Delta K)^{3,31}$, whichcan be found in the sample cast at 11,7 *rps* with a T6 heat treatment (11.7RPS-T6), and the highest value is $da/dN = 7x10^{-12}(\Delta K)^{3,62}$, which occurred in the sample cast at a 6,7 *rps* rotation speed (6,7RPS-T6).

Table 2 **Paris constants**

Specimens	Number of cycles / N	Paris Constant	
		C	n
6,7RPS-NT	368010	$3x10^{-12}$	4,166
8,3RPS-NT	329092	$4x10^{-12}$	3,989
10RPS-NT	387580	$3x10^{-12}$	3,984
11,7RPS-NT	428200	$5x10^{-12}$	3,671
6,7RPS-T6	532808	$7x10^{-12}$	3,620
8,3RPS-T6	472960	$8x10^{-12}$	3,508
10RPS-T6	662213	$7x10^{-12}$	3,426
11,7RPS-T6	878650	$4x10^{-12}$	3,310

Table 2 shows the Paris constants (*C* and *n* value), which indicate a low crack growth rate in aluminum scrap alloy when rotation speed increased after T6 heat treatment. Increasing the rotation speed improves the value of the fatigue crack growth rate. Moreover, the material's fatigue properties canbe improved further by T6 heat treatment. The plotting of (*da/dN*) vs. (ΔK) shows that the fatigue crack propagation rate is in Region II. The value of the Paris constant (*C*) can be determined by extending the line until it intersects with the vertical axis at $\Delta K = 1\ MPa.m^{1/2}$, where n represents a gradient of lines from the trend line curve.

CONCLUSIONS

The characteristic of fatigue crack growth rate of the recycled aluminum alloy by increasing of rotation speed during the centrifugal casting process and T6 heat treatment had been evaluated. The Increasing of rotation speed during centrifugal casting can increase tensile properties and material density but reduced the porosity of aluminum scraps. It would be affected by fatigue crack growth becoming low rate. The T6 heat treatment significantly increases the tensile stress then reduce fatigue crack growth rate. It changed the morphological of microstructure and formed precipitates around grain boundaries. Recycled aluminum alloys can be improved with increasing rotation speed of centrifugal casting then followed by T6 heat treatment to produce motorcycle cast wheels.

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Note: The responsible English translator is Peter D'Auria - the Language Center, Syiah Kuala University, Indonesia