Pre-heating of multi-axial forging (MAF) on aluminum based composites

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Pre-heating of multi-axial forging (MAF) on aluminum based composites

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Abstract. Aluminum is one of the materials used for automotive, almost 90% of aluminum scrap from automotive cars can be recycled. The properties of aluminum are light and have a high ductility. The addition of SiC as reinforcement to aluminum based composite materials by multi-axial forging (MAF) is one of the newly developed SPD processes. Addition of SiC is to increase strength greater than the base material. The purpose of this research is to know the micro structure especially spread of distribution of precipitate evenly in matrix and change of mechanical properties after MAF process. Therefore, variation of weight fraction of SiC and pre-heating temperature were conducted. Kind of aluminum type AA1100 shaped plate as matrix added SiC as reinforcement, using variation 0.2%:0.4% and 0.6% wt. As for pre-heating temperature variation of 350ºC, 450ºC and 550ºC then done MAF process with every change of pass rotate 90º. The results obtained from aluminum-based composite study by MAF, that with the addition of SiC on microstructure observation there is a change of grain boundary shape from equaxial to lamellar, there are grains of precipitate on the matrix that spread evenly and tensile test results and microhardness test increased along with the addition SiC fraction at a temperature of 350ºC while for temperatures of 450ºC and 550ºC there is a decrease in hardness value, tensile strength value on Al/SiC.

1. Introduction

The Indonesian automobile manufacturers association (Gaikindo) showed that motor vehicle sales in Indonesia amounted til 86,234 units, a year-on-year increase of 17.7%. Gakindo predicts sales will reach 1.1 million units seen from infrastructure and increase commodity prices, will help increase demand for cars [1]. The use of aluminum in automotive cars has many advantages including a fast, safe, and cost-effective process, in addition, the benefits of using aluminum in the car automotive is environmentally friendly. Almost 90% of aluminum scrap from automotive cars can be recycled. Recycling 1 ton of aluminum can save energy equivalent to 21 barrels of oil. The energy department at Oak Ridge National Laboratory found that vehicles with aluminum materials could reduce 20% of total energy cycle consumption and reduce 1% of CO_2 emissions [2]. Properties of aluminum are: high ductility, light weight, corrosion resistance and low strength so easily formed. AA1100 has a very high ductility with adequate strength. To increase the power up to 290 MPa in automotive applications it is necessary to add silicon carbide (SiC) by severe plastic deformation (SPD) [3]. Some SPD processes: equal channel angular pressing (ECAP), accumulative Roll Bonding (ARB), high pressure torsion (HPT) and multi-axial forging (MAF) are the development of conventional forming. MAF processing on automotive component are more appropriately selected for the process. The advantages of MAF method when compared to other methods in SPD, this process can be used for large materials and can be combined for mass production in industries with relatively low cost [4-6]. In most studies, the application of MAF is used for metals and alloys.

In this study, MAF was applied to the processing of aluminum-based composite with SiC as reinforced, variation of 0.2, 0.4, and 0.6% SiC weight fraction and using 350, 450 and 550°C processing temperatures, the results obtained were analysed to obtain ideal mechanical properties as recommendations for automotive components.

2. Experimental Methods

First step cutted aluminum plate AA 1100 with size 135 mm x 25 mm x 3 mm and 3 mm of thickness. The sample brushed using a wire brush with the same direction. Before the grinding process was done, the material is first cleaned using acetone solution. The acetone to prevent the material from getting dirt so no oxidation and then holes on each edge of the sample, The next step, done grinding and then sprinkling SiC powder 0.2% wt, 0.4% wt, 0.6% wt surface plate to bind the end plate used wire or rivet process. The pre-heating process was done in the muffle furnace used 3 time variables of choice: 350°C, 450°C and 550°C holding time of 1 hour. After preheating process aluminium directly done by pressured of MAF process.

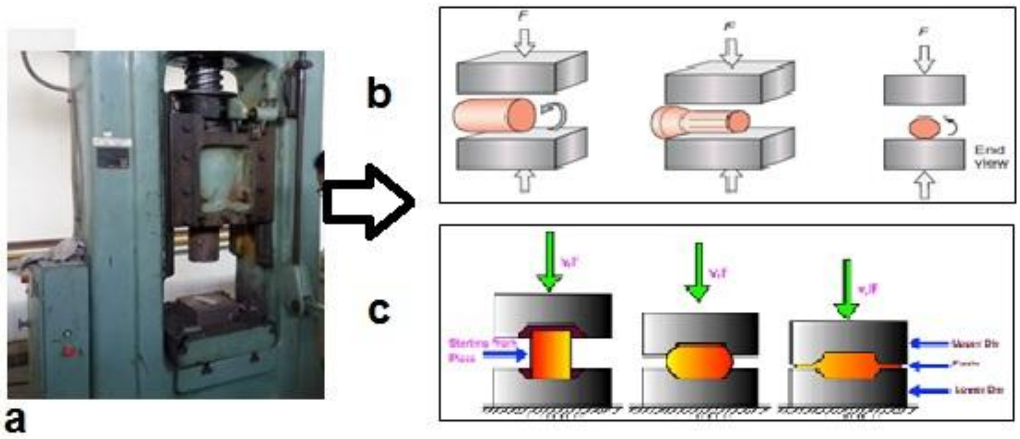

Figure 1. a) Multi-axial forging machine, b) Scheme of open die drop Multi axial forging process, c) Scheme of close die drop multi-axial forging process.

Figure 1 presented MAF machine were used to process aluminum-based composite materials, there are two types of division that are open and close dies of MAF. In this experiment use type open die MAF. The material is placed into the hydraulic press tool using a clamp as a tool, to pick up and remove the sample from the muffle furnace to the hydraulic press machine, as well as the handle while the sample is in forging. How to use this machine is by lifting the lever first to raise the load forging up to 100 kN. MAF process is done as much as 5 passes of pressed with direction rotation 180° final reduction reach 50%. The initial thickness of the material before the MAF process is 6 mm and the final thickness after MAF process reaches 3 mm.

3. Result and Discussion

3.1. Microstructure analysis

Observation of microstructure was conducted using optical microscope 200x magnification and image-J software for calculate of grain size, this is done to see and know the microstructure formed especially formation of bond formed between aluminum as a matrix with SiC particles. The aluminum microstructure as received shows the grain boundary in the shape of equiaxial and the grain size at the initial condition is still large and rough with the average grain size of 10.035 µm, shown in Figure 2a. The aluminium based composite microstructure with 0.6 wt% SiC at 350ºC for 5 pass formed precipitate grains that spread evenly within the matrix with lamellar grain boundaries and had an average grain size of 1.197 µm. Temperature 350ºC in Figure 2 b. it is seen that the sample has a bonding interface, where the interface bonding area contains SiC particles trapped in the interface bonding area. Figure 4.2 (c) shows a temperature condition of 450ºC with a 0.6% wt SiC fraction formed of lamellar granules with an average grain size of 1.81 µm where the number of precipitate grains is not as highest on 350ºC, the spread of precipitation grains at this temperature is spread evenly across in the matrix of this sample the grains begin to shrink and smooth. Figure 4.2 (c) shows a larger bonding interface when compared to the results of Fig. 2. b. Figure 4.2 (d) shows an optical microscope at 550ºC with a fraction of 0.6% wt SiC. The bulb is lamellar with an average buitr size of 1.987 µm, where at this temperature there is a fine prep filipipate and not all parts of the matrix are filled by precipitate grains. this indicates the presence of bonding interfaces and more SiC particles trapped in the interface area.

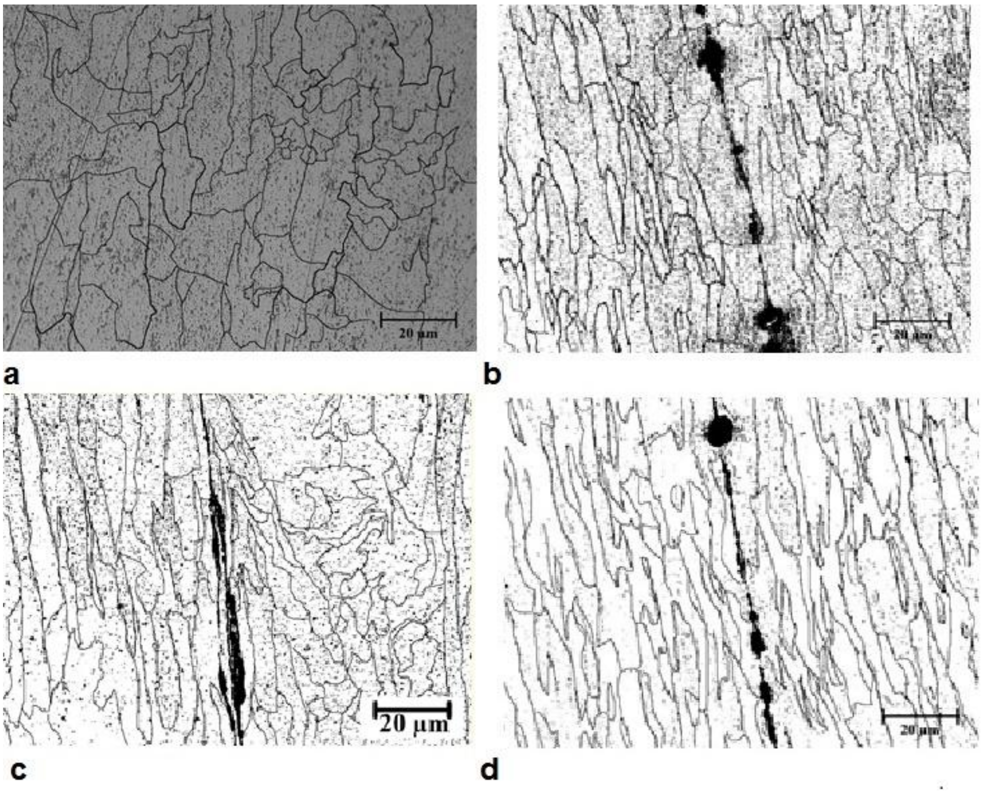

Figure 2. Result of microstructures a) Al as received, b) Al based composites by MAF pre-heating 350^{o}C, c) Al based composites by MAF pre-heating 450^{o}C, and d) Al based composites pre-heating 550^{o}C.

The result of optical microscope in each temperature still has a bonding interface. Addition of SiC on aluminum fraction can increase the strength and hardness value, that can be seen from the grain size produced. Increase of mechanical properties occurs because the reduction of thickness in each sample causes the particles in the interface layer to move, this will result in changes in grain boundary shape from equaxial to lamellar after MAF process. At the same time, the aluminum matrix moves between particles and causes the particles to separate from each other. The mechanical properties of the composites are strongly influenced by the presence of bonding interfaces, the presence of SiC particles in the aluminum layer interface causes a reduction in bond strength and this stage of the particles is not distributed in the matrix. Increasing the number of cycles in the SPD gives the effect of spreading SiC particles from the interface to most of the aluminum layers, all discontinuities in the interface disappear as a result of porosity closure. With the cyclical emphasis the thickness of the layer interface and SiC particles are scattered across most of the aluminum matrix. It show the dispersion of SiC particles in aluminum matrix becomes more uniform [7-9]. In the process of MAF 5 pass shows the result of spreading the grain structure evenly. The grain forming mechanism is part of dynamic recovery, under which conditions small grain sizes remain constant and incorrectly oriented granules will increase. There are two factors supporting the dynamic recovery of Al/SiC composite which is the shear deformation and micro particles size. When composites are exposed to deformation, the presence of non-deformable particles induces a stretch around the region causing the particles to form a new boundary due to the high density of dislocations [10-11].

3.2. Microhardness

The hardness as received was 34.6 HV. The highest hardness 45.62 HV produced by pre-heating process 350˚C with fraction 0.6% wt of SiC. While for lowest hardness value reach 37.12 HV at temperature 550˚C, with fraction of SiC 0.6 % wt. The results of Al/SiC composite hardness in the MAF process can be seen in Table 1.

Table 1. Formatting sections, subsections, and subsubsections

***Pre Heating* (˚C)**	**Percent SiC (% wt)**	**Microhardness (HV)**
As Received	**No**	34.6
350˚C	0.2	43.04
	0.4	43.08
	0.6	45.62
450˚C	0.2	41.40
	0.4	40.72
	0.6	37.86
550˚C	0.2	40.66
	0.4	40.74
	0.6	37.12

Several studies had shown an association between microhardness and microstructure, generated through various SPD processes. To determine the uniformity of deformation, the value of microhardness was measured at cross-section with the distribution that can be expected occured homogeneous microstructure at various SiC fractions. Samples before treatment and after MAF process had a mean hardness of 30-40 HV [7]. At 350°C the mechanical properties are affected by the addition of SiC fraction. In accordance with [10] the addition of SiC plays a very important role in increasing the hardness of a material because the SiC composite has a role as an reinforcement. As the SiC fraction increases, the resulting hardness value decreases. Pre-heating exceeds the optimal limit where the optimum temperature during heating for AA1100 is 0.3Tm – 0.5Tm [12] so that recovery time is saturated where the balance between hardening and softening has been reached. The increase of grain boundaries at low temperatures becomes a barrier where the area is considerably increased rather than coarse grain. Therefore, nanocrystalline metal alloys are expected to have higher mechanical properties than polycrystalline materials of the same composition [13]. Some of factors can be affect for Al based composite when the samples was dry and brushing before it is attached, strain hardening due to friction between the load and the specimen, grain refinement by dynamic recovery. Microhardness increases during initial pass due to strain hardening (based on dislocation density and dislocation effect with each other [14]. Dynamic recovery at high voltage can cause absorption of dislocations to more grain boundaries. Density dislocations of aluminum will decreases with increasing pressure and some free grain from dislocations after large deformations. Hardness of Al/SiC was greater than aluminum samples without the addition of SiC particles, because of resistance in SiC particle movement and strength of the bond between matrix and SiC particles increases. The pass number on SPD produces a more uniform distribution and reduces porosity content [15-16].

3.3. Tensile strength

Temperature of 450˚C and 550˚C there was a decrease in the tensile strength value of the fraction 0.2 wt to 0.6 wt. The lowest strength value of the temperature is 550ºC with SiC fraction 0.4% at 99.804 MPa. Previous researchers have proved that increasing the amount of SiC in the aluminum matrix can increase the tensile strength. It can be seen at 350˚C which shows an increase in tensile strength. This is related because SiC acts as an amplifier in the aluminum matrix. The difference in results at 350˚C with a temperature of 450˚C and 550˚C is due to the influence of the preheating temperature where temperatures of 450˚C and 550˚C experience maximum heating (overheating).

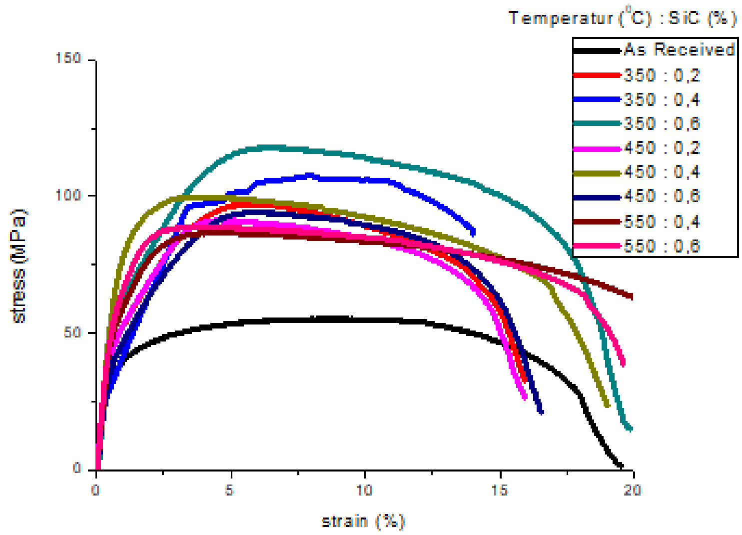

Figure 3. Diagram Stress-Strain Al based composite by MAF.

Temperature on 400°C for composite by SPD is a dynamic recrystallization temperature where the stored energy will produce new nucleation of granules, nucleation starts from the beginning of the formation of dendrites as grain growth [17]. The highest UTS value at 350ºC with a SiC fraction of 0.6%. It was explained that increasing the SiC fraction can affect the material strength of the ARB process due to ultrafine grained and strain hardening processes (dislocation tightening). Grain size depends on the level of accumulation of strain that is affected due to dynamic recovery and work temperature which will determine grain growth. Strain hardening causes a large increase in the amount of dislocation density so that the dislocation movement will be difficult to move. When dislocations move, there is a buildup of dislocations at the grain boundaries and lattice defects or because the dislocations move on different slip fields causing interlocking and making dislocations difficult to move [18].

The results of tensile test and elongation of Al/SiC composites, basically the tensile strength value will be inversely proportional of elongation. If the value of tensile strength increases, the results of elongation will decrease but different things can be seen at 350ºC where at that temperature the tensile strength value is directly proportional to elongation seen increasing while at temperatures 450ºC and 550ºC the value of tensile strength and elongation decreases can be seen in Figure 3. The value of tensile strength and elongation decreased with increasing SiC because the SiC particles had three main effects, namely (1) during the tensile test, the SiC particles acting independently of the dislocation movement resulted in increased strength, (2) the presence of SiC particles in the aluminum matrix resulted in more dislocations to gather in their area, because the particles cannot be changed and the matrix undergoes plastic deformation so that the strain mismatch is produced between the particles and the matrix. Strain mismatch causes dislocations to be stored near the particle-matrix interface [9] (3) SiC tensile strength is about 27 times greater than aluminum, therefore, dislocation density on the matrix near the interface between aluminum particles and SiC increases [14]. When the SiC phase in the matrix increases the dislocation movement will be obstructed which causes a decrease in elongation value. If the SiC particles in a brittle state cause matrix with particle constraints that can change the local state of stress.

4. Conlussion

Based on the research that has been done, it can be concluded that:

1. Hardness decreases as the preheating temperature increases because the higher of preheating temperature produces the larger of grain size.
2. Tensile strength increases by addition of SiC particles. Elongation value cannot be used as a reference because the data produced varies. Eelongation value due to uneven spread of grain.
3. The pre-heating of temperature produced the larger the resulting bonding interface diamètres. This is evidenced by the increased bonding interface diameter of 36.304 μm

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