Temperature and strain rate effect on flow stress of al2075/bottom ash composite

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Abstract. This study focused to determine the flow stress of Al 2075 composites with bottom ash reinforcement. Metal forming process is very important in an industry, materials can be plastic deformed requires several parameters of the forming process, such as the material flow stress. Temperature and strain rate affect the flow stress material. In this paper the tensile test carried out at 350°C, 400°C and 450°C and the strain rate varied 1 mm.s⁻¹, 10⁻¹ mm.s⁻¹ and 10⁻² mm.s⁻¹. Tensile test showed that the highest flow stress is obtained at 350°C and a draw rate of 1 mm.s⁻¹, the higher the temperature will decrease the flow stress, while the faster the strain rate increased the material flow stress.

1. Introduction

Metal matrix composite (MMC) is combination of two or more materials, commonly used oxide ceramics, carbides and nitrides as reinforcement, whose main function is to support matrix receiving load [1]. Manufacturing of MMC used oxide materials such as SiO₂ and Al₂O₃ as reinforcement. Oxide materials require high production costs. One innovation to reduce production costs is the use of industrial waste as an aluminum matrix composite reinforcement. Bottom ash is the residual of the coal combustion process which is increasing every year. Bottom ash is an industrial waste that causes environmental pollution that is air and soil pollution [2].

Production of AMC composites with stir casting produces billet. Billet is material has easiest to form that can be produced in the AMC stir casting process. Billets have the disadvantage in economic field. However, AMC billets are an excellent material for the metal forming process. This is due to a good combination of strength, formability and response in surface treatment [3]. The forming process is important in a metal industry. The material is able to plastic deformation if the flow stress known [4]. Flow stress in the metal forming is influenced by operating temperature, strain rate [5]. This means that changes in temperature and strain rate affected the flow stress.

Tensile test on Al6061/Bottom ash with temperature variations at 500°C, 550°C, 600°C and 10⁻⁵, 10⁻⁶, 10⁻⁷ mm.s⁻¹ strain rates, it indicating higher temperature can accelerate the increase in material length and rate slow strain causes longer accretion [1]. Tensile testing in temperature 850°C, 900°C and 950°C shows that the higher the temperature decreased the maximum tensile stress and the flow stress of S48C steel [6]. Tensile test results at 100°C, 150°C, 200°C and 250°C showed that decrease in tensile strength from 605,820 N/mm² to 446,570 N/mm² [7].

Al 2075 composites with bottom ash reinforcement need to know their flow stress, so that the metal forming process can be carried out. The effect of strain rate and temperature on the composite flow stress is the focus of this paper. The optimum formation parameters expand the widespread the application of Al 2075/ Bottom ash composite in the automotive, aviation and marine [8].
2. Materials and Method

The aluminium 2075 matrix has been obtained from various automotive brand pistons. 10%wt bottom ash used as composite reinforcement. Bottom ash was treated with electroless coating process. Magnesium fine powder with 1%wt added as a wettability agent. The tensile test conducted followed ASTM E8 with variations of temperature at 350, 400, and 450°C and variation strain rates of 1, 10⁻¹ and 10⁻² mm.sec⁻¹.

Electroless coating process has been carried out by adding 200 g of bottom ash, 0.5 g of Al fine powder, 120 ml of HNO₃ and 0.1 g of Mg fine powder. The solution was stirred for 1 hour at 100°C, and then dried at 100°C for 1 hour for the oxidation process. Gravity casting has worked with 10%wt of bottom ash and 1% Mg. Stirring was carried out at 500 rpm for 15 minutes. Then Slurry has been poured into a permanent mold.

| Table 1 Experiment codification |
|---------------------------------|
| Temperature (°C) | Strain rate (mm.s⁻¹) |
|                  | 1               | 10⁻¹          | 10⁻²          |
| 350              | A1             | B1            | C1            |
| 400              | A2             | B2            | C2            |
| 450              | A3             | B3            | C3            |

3. Result and Discussion

Fig. 1 shows that the higher the tensile test temperature the flow stress decreases. Fig. 1(a) shows that the highest flow stress is reached at 350°C with a strain rate of 1 mm.sec⁻¹, flow stress is 48.45 Kgf/mm². At 400°C with a strain rate of 1 mm.sec⁻¹, the flow stress decreases to 48.3 Kgf/mm². At higher temperatures with a strain rate of 1 mm.sec⁻¹, the flow stress decreases to 45.72 Kgf/mm².

Fig. 1(b) showed that the highest flow stress is reached at 350°C with a strain rate of 10⁻¹ mm.sec⁻¹, flow stress is 48.17 Kgf/mm². Higher temperatures the flow stress decreases to 47.04 Kgf/mm² and 44.4 Kgf/mm² respectively. Fig. 1(c) showed that the highest flow stress is reached at 350°C with a strain rate of 10⁻² mm.sec⁻¹, flow stress is 47.53 Kgf/mm². Higher temperatures the flow stress decreases to 46.45 Kgf/mm² and 43.45 Kgf/mm² respectively.

The phenomenon of the decrease in flow stress at higher temperatures occurs due to softening when the material given heat, the heating causes softening and rearrangement of the arrangement of atoms in the material (order-disorder material) so that the mechanical properties of the material such as hardness and strength change [9]. Tensile testing results show the higher the temperature decreases the flow stress [6]. The plastic flow properties of materials is depends to function of temperature and strain rate [10]
Figure 1 Effect of temperature on flow stress of Al2075/Bottom ash composite:
(a) 350°C. (b) 400°C. (c) 450°C.

Figure 2 Effect of strain on flow stress of Al2075/Bottom ash composite:
(a) Strain rate 1 mm/s. (b) Strain rate 0.1 mm/s. (c) Strain rate 0.01 mm/s

Figure 2 shows that the increase in the strain rate of the tensile test then the flow stress is increasing. Figure 2a shows that the flow stress at 350°C with a strain rate of 1 mm.s⁻¹ produces the highest flow stress of 48.45 Kgf/mm² compared to the other strain rates. Tensile test with strain rate of 10⁻¹ mm.s⁻¹ d the flow stress drops by 0.7% to 48.17 Kgf /mm². The strain rate of 10⁻² mm.s⁻¹, the flow stress drops 1.9% to 47.53 Kgf/mm². Figure 2b shows that the flow stress at 400°C with a strain rate of 1 mm.s⁻¹ produces the highest flow stress of 48.3 Kgf /mm² compared to the other strain rates. Lower strain rate the flow stress decrease to 47.04 Kgf /mm² and 46.45 Kgf/mm² respectively. Figure 2c shows that the flow
stress at 450°C with a strain rate of 1 mm.s⁻¹ produces the highest flow stress of 45.72 Kgf/mm² compared to the other strain rates. Lower strain rates resulted the flow stress decrease to 44.4 Kgf/mm² and 43.45 Kgf/mm² respectively.

Increased strain rates resulted higher flow stresses [11]. Increased strain rate causes higher strain hardening, then higher stress needed to overcome the strain hardening, so that with increasing strain rate the material stress increases [6]. There are some possible mechanism in strengthening: (i) Finer grain in the material, (ii) increasing in dislocation (iii) The Orowan mechanism, (iv) The load transfers effect [12]. The combined effect of strain rate and temperature is shown in Figure 3.

![Figure 3](image-url)

**Figure 3** Effect of tensile test temperature and strain rate on flow stress

4. Conclusion

1. The increase in temperature affects the material flow stress. The higher the tensile test temperature, the flow stress decreases.
2. Strain rate affects the material flow stress, the higher the strain rate the flow stress increases.

References

[1] Seputro H, Ismail, Chang S H, Superplasticity of bottom ash reinforced aluminum metal matrix composite Mater. Phys. Mech. 37 205–211.
[2] Nizar I K, Al Bakri A M M, Rafiza A R, Kamarudin H, Alida A, Zarina Y 2014 Study on physical and chemical properties of fly ash from different area in Malaysia Key Eng. Mater. 594–595.
[3] Rayset J, Tundal U, Espezel C, Reiso O 2019 Al-Mg-Si billets with high extrudability - State of the art and beyond Mater. Today Proc. 10 185–192.
[4] Altan T, Boulger F W 1973 Flow Stress of Metals and Its Application in Metal Forming Analyses. ASME Pap. doi:10.1115/1.3438245.
[5] Gangolu S, Rao A G, Prabhu N, Deshmukh V P, Kashyap B P 2014 Effects of temperature and strain rate on compressive flow behavior of aluminum-boron carbide composites J. Compos. Mater. 48 1313–1321.
[6] Priadi D, Setyadi I, Siradj E S 2010 Pengaruh Kecepatan Dan Temperatur Uji Tarik Terhadap Sifat Mekanik Baja S48C MAKARA Technol. Ser. 7 21–26.
[7] Asfarizal 2008 Pengaruh temperatur yang ditinggikan terhadap kekuatan tarik baja karbon rendah, TeknikA.
[8] Akbar H I, Surojo E, Ariawan D 2018 Effect of quenching agent on dimension stability of Al 6061-Al2O3composite MATEC Web Conf. 159.
[9] Smallman R E 1999 Modern Physical Metallurgy and Materials Engineering Mod. Phys. Metall.
[10] Sastry D H, Prasad Y V R K, Deevi S C 2001 Influence of temperature and strain rate on the flow stress of an FeAl Alloy Mater. Sci. Eng. A. A 299 157–163.
[11] Reddy A C 2011 Influence of Strain Rate and Temperature on Superplastic Behavior of Sinter Forged Al6061 / SiC Metal Matrix Composites 4 189–198.
[12] Yoo S J, Han S H, Kim W J 2013 Strength and strain hardening of aluminum matrix composites with randomly dispersed nanometer-length fragmented carbon nanotubes Scr. Mater. 68 711–714.