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Original Article

Hardness, tensile and impact behaviour of hot forged aluminium metal matrix composites

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ABSTRACT

Tensile and impact testing and hardness measurements were carried out on hot forged aluminium metal matrix composites to understand the influence of alloying element and forming process on their mechanical properties. Pure aluminium preforms together with its composites such as Al4TiC, Al4Fe_3C, Al4Mo_2C and Al4WC were prepared using a suitable die-set assembly on a 1 MN capacity hydraulic press. Sintering operation was carried out in an electric muffle furnace at the temperature of 1200 °C for a holding period of 1 h. Immediately after the sintering process the cylindrical preforms were hot deformed in to a square cross-section bar of size 24 mm × 24 mm × 60 mm for preparing of tensile test and impact test specimens as per the respective ASTM standards. Standard tensile and impact test specimens were machined from the forged square rods. Standard ASTM procedure was followed to conduct the aforementioned mechanical testing. Further, microstructural studies on the hot forged square cross-section bar and hardness measurements were obtained and analysed.

1. Introduction

Two most generally used manufacturing route for metal matrix composites are casting techniques and powder metallurgy (P/M) techniques [1]. The automotive and off-highway vehicle applications take over the ferrous P/M structural parts market. Particularly, low alloy steels are a familiar structural material for systems such as power plants, aircraft and naval industries or bearing material [2]. These alloys show excellent mechanical properties, low distortion and excellent weldability. They can be fabricated in various shapes such as bars, wires, sheets, forged parts, casts and powder metallurgy products. The presence of pores after the pressing and sintering process of metal powders is a limiting factor in the production of powder metallurgy (P/M) parts. Indeed, the mechanical properties such as tensile, hardness and impact strength are significantly influenced by this inherent porosity. Sintered

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Table 1 – Characterization of aluminium powder and its blends.

Property	Al	Al-4%WC	Al-4%TiC	Al-4%Fe_3C	Al-4%Mo_2C
Apparent density (g/cc)	1.091	1.345	1.186	1.308	1.325
Flow rate, (s/50 g) by Hall Flow Meter	87.306	79.647	85.202	80.559	80.481
Compressibility (g/cc) at pressure of 130 ± 10 MPa	2.356	2.113	2.280	2.235	2.210

P/M preforms are particularly prone to fracture during forging because high amounts of pores in the preform act as stress risers. This is true for many P/M engineering components such as cam shaft pulleys, gears, sprockets, connecting rods, nozzles, pump parts, etc. [3,4]. These components during service are subjected to impact loads, tensile loads, torsional loads and compressive loads and the study of the mechanical behaviour under these loads is of great importance. Little research is conducted in the past on the mechanical behaviour of P/M aluminium metal matrix composite. In particular reinforcements such as iron carbide, molybdenum carbide and tungsten carbide provided the motivation to conduct this research.

Danninger et al. [5] have presented the relationship between apparent density, Vickers hardness and tensile strength in P/M iron and steels sintered at standard temperatures. It has been reported [6–8] that the tensile, impact and fatigue properties of sintered steels are greatly influenced by sintering temperature, sintering time and compacting pressure. Dudrova and Kabatova [9] have presented that a fracture surface depicts the evidence of loading history, the defects caused by friction, alloy compositions or processing technology as well as microstructure characteristics and the necessary changes in the processing technology of the structural parts can be made from these analyses. Further, it has been reported [10,11] that the micromechanisms of fracture are strongly influenced by the matrix characteristics, the deformation rate and the presence of a notch in the test specimen. Toughness and hardness properties of high density sintered steel (Fe–4.0Ni–1.5Cu–0.5Mo–0.5C) have been studied by Moon [12]. It has been reported that both strength and toughness are also affected by the local strengths, ductilities and work-hardening characteristics of the necks, which in turn are functions of their local composition and microstructure. Trivedi et al. [13] and Rahimiana et al. [14] have evaluated the effect of composition and particle size, sintering temperature and sintering time on iron and aluminium alloys, respectively. It has been reported that as the particle size of alumina is reduced, the density is increased followed by a fall in density. In addition, at low particle size, the hardness and yield strength and compressive strength and elongation to fracture were higher, as compared to coarse particles size of alumina. A study by Srivatsan et al. [15] indicated that increasing the SiC in the aluminium metal matrix composite results in the high fatigue strength. Further, 15 wt.% SiC showed the highest fatigue strength. They also showed that the non-uniform distribution of the reinforcing particulate caused the crack propagation at low values of applied stress. Another method of improving mechanical properties of sinter-hardened steel is post sinter tempering treatments to achieve specific structural performance goals [16,17].

Table 2 – Sieve size analysis of aluminium powder.

Sieve size (μm)	250	+200	+150	+100	+75	+45	−45
Retention in sieve (wt.%)	0.2	0.3	16.3	55.3	9.5	7.9	10.5

Thus the present investigation is aimed to investigate the influence of high strength carbide particles addition on the mechanical properties of sintered powder metallurgy composite aluminium preforms during hot forging. Most powder metallurgy components produced after the primary process and even after the secondary operations are likely to achieve 85–92% theoretical density. Therefore, the strength of the powder metallurgy component such as tensile strength, impact strength, yield strength, etc. will be in the range of 65–85% theoretical maximum. Hence, a challenge for researchers in this field is to achieve higher relative density by applying innovative compaction and secondary deformation process and to increase the strength of the material by designing frontier materials by carefully selecting process parameters.

2. Experimental

2.1. *Materials and characterization*

Aluminium powder of diameter less than 150 μm and carbide powders of diameter less than 50 μm were used in the present investigation. The characteristics (apparent density, flow rate and particle size distribution) of aluminium powder, Al4TiC, Al4Fe_3C, Al4Mo_2C and Al4WC blends are shown in Tables 1 and 2.

2.2. *Blending, compaction and sintering*

The powders were mixed using standard procedure by weight percentage to prepare Al4TiC, Al4Fe_3C, Al4Mo_2C and Al4WC blends using PM400A ball mill at 200 rpm for 2.5 h. Four compacts with initial relative density of 0.90 ± 0.01 of each composition were prepared using a hydraulic press where the pressure was determined first by plotting the compressibility curve of each composition. After the initial density verification, each compact was coated with alumina mixed in acetone. This paste was applied to avoid oxidation during the sintering process. Two coats were applied with 12 h drying period each time. After drying, the compacts were sintered in an electrical muffle furnace for a period of 60 min at 594 °C. Prior to this the compacts were dried at 220 °C in the same furnace for 30 min.