Mechanical characterization of precipitation hardened Al7075-grey cast iron powder reinforced metal matrix composites

Jamaluddin Hindi [1*], *Kini Achuta*[1] and *Murthy Amar*[1]

[1]*Department of Mechanical and Manufacturing Engineering, Manipal Institute of Technology, Manipal Academy of Higher Education, 576104, India*

Abstract. Al7075 alloy is the most commonly used by the aerospace industry. Al7075 alloy is characterized by its improved properties such as higher toughness, specific strength and hardness. The current work focuses on the preparation and characterization of age hardened Al7075-Grey cast iron composites. Two stage stir casting technique is used for the preparation of the composite. Age hardening treatment is imparted to enhance the mechanical characteristics. The variation of hardness and tensile strength with respect to aging temperature and percentage of reinforcement is analyzed. The composites exhibit higher hardness and tensile strength as the reinforcement percentage is increased at an aging temperature of 100^0C.

1 Introduction

Composite material is a combination of dissimilar materials which result in property enhancement than those of the individual elements. There will not be any change in the chemical, physical, and mechanical properties of individual elements i.e. matrix and reinforcement [1-4]. Composite materials are characterized by high strength to weight ratio, higher stiffness with low density resulting in considerable reduction in the weight of the component. Enhancement in the desirable properties is mainly due to the reinforcement which is generally harder, refractory, and stiffer than the base material [5]. The reinforcement phase can be continuous or discontinuous fiber or particulate. Metal matrix composites can be defined as a combination of two or more dissimilar materials, one of which is a metal, in which enhancement of desirable properties are achieved by systematic combinations of different constituents [6-8]. Very high specific strength and specific modulus can be achieved in MMCs consisting of continuous or discontinuous fibers, whiskers, or particles [9].

[*] Corresponding author: jamalhindi@gmail.com

Aluminum alloy composites are hardened by reinforcement of ceramic refractory particulates into the base matrix material. Due to their innate nature and creation of nucleation sites in the matrix material, reinforcements can enhance tensile related properties of the matrix material [10-12]. Particulate reinforced composites are characterized by economic manufacturing methods with finer grains. Selection of the type of reinforcement is based on the property enhancement and monetary investment [13,14]. Generally, continuous fiber reinforced MMCs have unidirectional properties in the direction of the fiber, but are costly. Chopped fibers can produce significant property enhancement in the two dimensionally in the direction of their orientation, at moderate cost. MMCs provide moderate but isotropic properties [15-19].

Grey cast iron is one of the types of cast irons which have unique microstructure containing carbon in free and combined form. Carbon is present as cementite and graphite. The weight percentage of these two constituents can be altered by the addition of graphite formers like Si. The fractured surface of the grey cast iron specimen is greyish in colour due to the presence of free carbon as graphite and combined carbon as cementite. The graphite also provides gray cast iron with an additional damping capacity for the alloy or matrix since it absorbs the energy [21-23].

2 Materials and methods

2.1 Al 7075 alloy

Al7075 alloy is the most commonly used by the aerospace industry. Al7075 alloy is characterized by its improved properties such as higher toughness, specific strength and hardness. The Al-Zn-Mg alloys [Al7075] are used in as cast and age hardened condition. As cast alloys are generally homogenized. Table 1 shows the chemical composition of Al7075 alloy [20].

Table 1. Chemical composition of Al7075 alloy.

Al	Cr	Cu	Fe	Mg	Zn	Si	Mn	Ti	Others
89.79	0.08	1.35	0.3	2.21	5.67	0.4	0.08	0.06	0.06

2.2. Grey cast iron

The chemical composition of grey cast iron is shown in table 2.

Table 2. Chemical composition of the grey and cast iron (wt.%).

Element in wt.%	C	S	P	Si	Mn	Fe
GCI	3.61	0.024	≤0.022	1.30	0.41	Bal

Grey cast iron has good potential as a reinforcement material due to following reasons:

- It is also an industrial waste which comes in the form of chips during machining operation. These chips can be re casted to be used as reinforcement.
- Grey cast iron is hard due to the presence of cementite but also has high self-lubricating property and machinability due to the presence of free graphite in the form of flakes.
- It serves as a hybrid reinforcement because microscopically there are three phases in GCI at room temperature i.e. cementite, ferrite and graphite.
- It will not react with Al7075 which will be used as a base matrix material.

2.3. Preparation of the reinforcement phases

Grey cast iron (GCI) rod is cast using chill casting technique with secondary operation i.e. turning operation to machine the casting to remove foreign material inclusions near the mould wall and slag at the top of the casting. Hardness values at three sample zones of casting is measured using Rockwell B scale to analyse the homogeneity of hardness values of the sample. To achieve homogenous chemical composition and hardness, the specimen is annealed at 800^0C for 10 hours [24-26] The casting is turned in lathe to collect grey cast iron dust (debris), washed and preheated to 300^0C for 1 hour to remove volatile substances present. Debris is ground in planetary ball mill as shown in figure 2 to reduce the size of particles upto 50 μm and sieving is performed to obtain uniform grade of particles. Sieving and grinding cycles is repeated till the required quantity of uniform grade of particles are obtained. The particles were seived through ASTM-140 sieve to obtain uniform grade of particles of average size 50 μm [18].

2.4 Stir casting of Al7075–GCI composites

Al7075-T6 rods of 1 inch diameter and 7 inch length were procured from the supplier. It was cut to 1 inch length and required number of pieces were placed in the crucible and melted in a furnace at 750^0C. After complete melting hexa chloroethane was added as a degasification agent. Alkaline powder was added to remove the slag. Permanent mold cavities for cylindrical and flat billets are cleaned using a wire brush and are coated with graphite powder and water emulsion. Assembled molds were preheated to a temperature of 450^0C for an hour in a separate furnace. Reinforcement prior to the addition to the molten metal was separately pre heated to 450^0C to remove volatile substances [9]. Three compositions of the composite were prepared by varying the weight percentage of the reinforcement. Stirring of the molten metal was carried using a mechanical stirrer placed on top of the Induction furnace. Required amount of reinforcement was added to the melt through a funnel placed in position. Vortex was created by rotating the stirrer at suitable speed, two step stirring was carried out to overcome heat loss and drop in furnace temperature. After the completion of stirring the molten metal with reinforcements was poured to a pre heated permanent mold and allowed to solidify at room temperature.

3 Results and discussion

3.1 Measurement of Peak hardness

Peak hardness values are noted for all the compositions. Age hardening curves were plotted for each specimen at half an hour interval. From the analysis of age hardening curves it is evident that lower the temperature of aging, higher will be the peak hardness value. As the aging temperature is increased peak hardness can be obtained at a faster rate but sacrificing on the value of peak hardness. At both lower and higher aging temperature, material exhibits higher peak hardness as the weight percentage of the reinforcement is increased. Figure 1 and 2 shows Age hardening curve at lower and higher aging temperature at 100 and 200^{0}C. Figure 3 shows variation in peak hardness with respect to wt.% of GCI for as-cast and age hardened specimens.

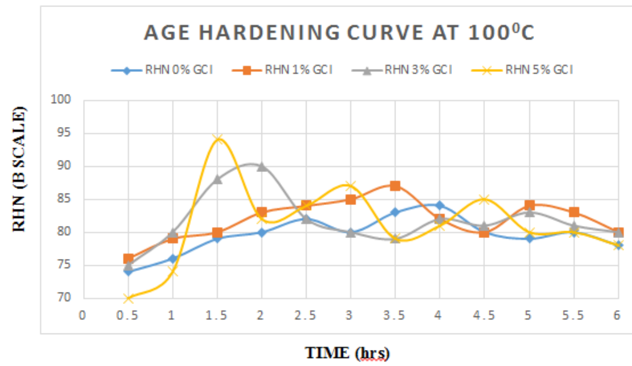


Fig. 1. Age hardening curve at lower aging temperature 100^{0}C.

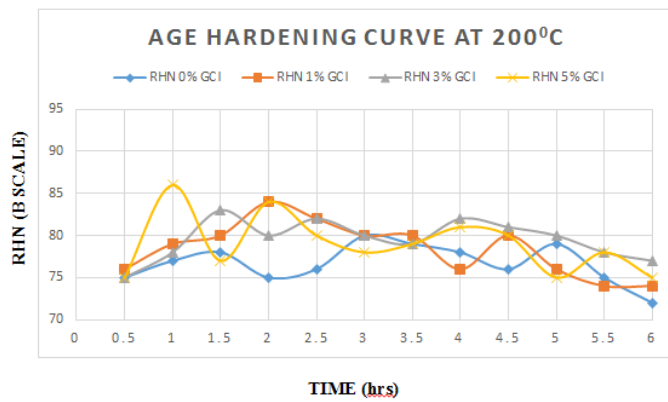


Fig. 2. Age hardening curve at higher aging temperature 200^{0}C.

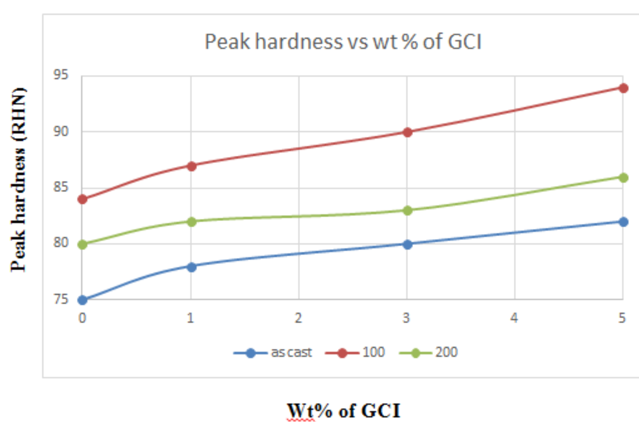


Fig. 3. Peak hardness vs wt.% of GCI for as-cast and age hardened specimens.

3.2 Measurement of tensile strength

From the analysis of the graph shown in figure, it is evident that lower the temperature of aging, higher will be the ultimate tensile strength value. At both lower and higher aging temperature, material exhibits higher ultimate tensile strength as the weight percentage of the reinforcement is increased. Figure 4 shows the variation in ultimate tensile strength with respect to wt.% of GCI for as-cast and age hardened specimens. The ductility decreases as the percentage of reinforcement is increased irrespective of the aging temperature as shown in figure 5.

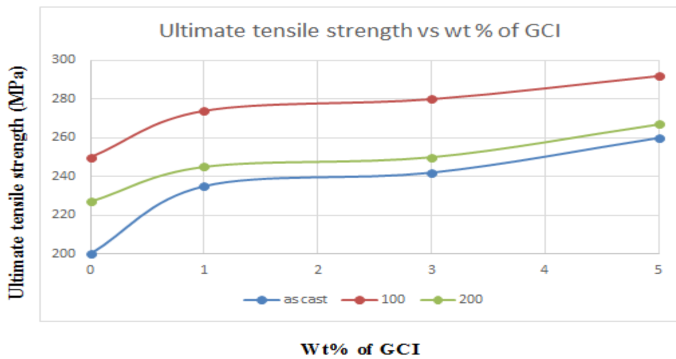


Fig. 4. Ultimate tensile strength vs wt.% of GCI for as-cast and age hardened specimens.

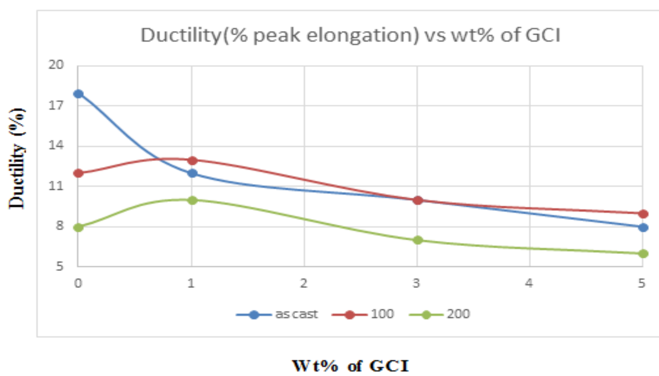
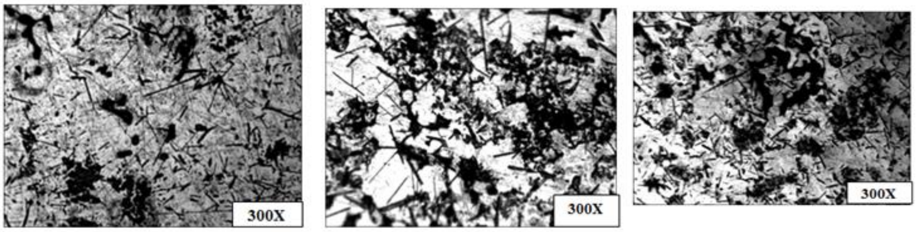


Fig. 5. Ductility vs wt.% of GCI for as-cast and age hardened specimens.

3.3 Microstructure analysis

The specimens are systematically polished with a series of silicon carbide embedded emery papers starting from coarser 100 microns to finer 600 microns in the steps of 100 microns. At every stage of polishing specimens are water washed and dried with acetone. Super finishing operation known as buffing is performed on disc polisher with wet diamond paste of 50 microns. Finally, the mirror like polished specimens is etched with etchant (Keller's reagent) [6]. Microstructures of all the samples are recorded in metallurgical microscope at 300X magnification. Figure 6 shows the microstructure of heat treated composites at 300X as recorded by ImageAnalyzer. Homogenised specimens show better dispersion of reinforcement without clustering.



(a) (b) (c)

Fig. 6. Microstructure of homogenized (a) AA7075 composite with 1% Grey cast iron powder (b) AA7075composite with 3% Grey cast iron powder (c) AA7075 composite with 5% Grey cast iron powder.

4 Conclusions

Al 7075 alloy can be successfully reinforced with grey cast iron powder using two step stir casting technique. Age hardening treatment significantly improves the mechanical properties of the composite material. Lower the aging temperature better is the peak hardness values in age hardening. Substantial improvement in the bulk hardness is observed in the composite with increase in the weight percentage of reinforcement. Substantial improvement in the ultimate tensile strength is observed in the composite with increase in the weight percentage of reinforcement. Peak hardness and maximum tensile strength was observed in Al 7075-5% GCI aged at 100^0C. The ductility decreases as the percentage of reinforcement is increased. The microstructure study reveals uniformity in the reinforcement distribution without any agglomeration.

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