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Experimental Studies on Heat Treated AA6061+GCI Composite

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Abstract

Objectives: To do the mechanical characterization of the composite developed by reinforcing the Grey Cast Iron (GCI) in AA6061. **Methods/Statistical Analysis**: An aging study was carried out on specimens of plain AA6061 matrix alloy and GCI reinforced AA6061 composite. Initially, samples were solution treated for 2 h at 550^{0}C, then quenching in water followed by artificial aging at 160^{0}C for different aging times. In the present study microstructure, hardness, tensile and impact properties of AA6061 based composite reinforced with GCI are analyzed as cast and in peak aged conditions. **Findings**: The presence of Grey Cast Iron in the matrix has resulted in improvement of the mechanical properties of the composite. The micrographs of the composite revealed a uniform distribution of the particles in the matrix. Comparison of the characteristics before and after heat treatment was done and it was found that there is an improvement in hardness, tensile strength of the composites as well as AA6061 alloy after heat treatment. It is found that the impact resistance reduces as the quantity of reinforcement is increased and also the cast specimens had better impact resistance than the peak aged category. Lowering of impact resistance is due to the loss of matrix ductility. **Application/Improvements:** The GCI reinforced particulate composites have been proved to be most suitable for heat and wear resistance applications.

Keywords: Characterization, Grey Cast Iron, Heat Treatment, Metal Matrix Composites, Particulates, Stir Casting

1. Introduction

The aluminium alloy reinforced composites rapidly replacing the conventional materials in various industries like aerospace, marine, and automotive[1]. Al and its alloys have been extensively used in casted and in wrought form with heat treatment in various applications. Forged parts, sections, extruded parts, sheets, plates, strips and wires are examples for wrought form and casted form are available as sand, pressure and gravity die castings[2].

Practically the most favorable alloys that can be dispersed in cast and wrought aluminium alloys for structural applications are Mg, Si, Mn, Cu, Zn. These dispersions can be used individually or in combined form. The dispersion of these elements will enhance the properties of plain alloy when added in appropriate percentages. The wrought Al alloys are designated as shown in Table 1[3].

A Metal Matrix Composite (MMC) is composite material with at least two constituent parts, one being a metal necessarily the other material may be a different metal or another material, such as a ceramic or organic compound[4].

In the present study GCI particles (30-50 μm) are added to AA6061 in 2% and 4% by wt. to produce two categories of composite. The presence of GCI in the Al alloy is expected to improve the properties.

Heat treating of Al alloys is normally limited to definite kind of operations used for improving the strength and hardness of Al alloys. Al alloys can be categorized

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Table 1. Standard terminology of Wrought Al alloy

Alloy Designation	Detail
1XXX	99% Pure Aluminium
2XXX	Cu as major element in alloy
3XXX	Mn as major element in alloy
4XXX	Si as major element in alloy
5XXX	Mg as major element in alloy
6XXX	Mg as major element in alloy
7XXX	Zn as major element in alloy
8XXX	Other alloys

as non- heat treatable and heat treatable alloys as all Al alloys are not suitable for heat treatment.

Wrought and cast forms of alloys can be subjected to Annealing heat treatment. The basic purpose of this treatment would be to enhance the ductility. Generally complete or partial annealing is done for non-heat treatable alloys[3]. Alloys of Al of this kind belong to the system having low solubility in the solid state and are known as precipitation hardeneble alloys[5]. The basic feature of this type of alloys category is that they have temperature dependent equilibrium solid solubility that increase as temperature is raised. Also the other feature is that they retain single phase super saturated solid solution by quenching and precipitation of coherent or partially coherent phase by decomposition of the super saturated solid solution.

Some of the types of these are as follows[6]:

2XXX series alloys, contain Cu and Mg as major elements that enhances the strength by age hardening.6XXX series alloys, which exhibit high weld ability property, high corrosion resistance and resistance to stress corrosion cracks and 7XXX series alloys, which are easily age hardened. There will be decrease in zinc solubility as the temperature is reduced. The resistance to stress corrosion cracking can be enhanced by addition of Cu to Al-Zn-Mg Alloys.

Few of the alloys will not respond to heat treatment as they contain homogeneous solid solution with or without any non-coherent precipitates and exhibit lower strength and higher ductility. These alloys will not have a decrement of solid solubility with reduction in temperature. Also strength can be enhanced only by cold working[7]. There exists even medium strength alloys used for extrusion components that have superior weld ability, resistance to corrosion and resistance to corrosion, corrosion stress cracking. AA6061 is a precipitation hardening aluminium alloy, having Mg and Si major elements. This alloy exhibits superior weld ability and mechanical characteristics. It is most commonly used alloy for general applications[8]. With the introduction of Mg the Al-Si alloys can be age hardened by the precipitation of Mg_2Si particles. The major Al alloy system is as shown in Figure 1. Of the many types of particulate reinforcements, grey cast iron is a type of cast iron that has a graphitic microstructure which can be used as reinforcement for Al alloys. It is most extensively used cast iron based on weight[9]. The age hardening or precipitation hardening is induced by sequential phase transformation that would lead to homogeneous distribution of Nano scale, coherent precipitates in a softer, more ductile matrix[10].

Age hardening process contains basically three stages like solution treatment, quenching and aging[11-13].

Solution treatment is the primary stage in age hardening process. To dissolve the secondary phases and to form uniform solid solution generally the alloy is heated above 550^{0}C. Quenching is the intermediate stage in age hardening process. Here alloy is rapidly cooled from the higher temperature one phase region to two phase region at atmospheric in order to form supersaturated solid solution and Aging is the last stage in age hardening process. Here the alloys will retain fine dispersions of small precipitates at the end of this stage.

The material selection criteria for an application involve the requirement of high strength and good corrosion resistance of aluminum alloys for the matrix materials[14]. The GCI reinforced composites can be used in the applications requiring high strength and resistance to heat and wear.

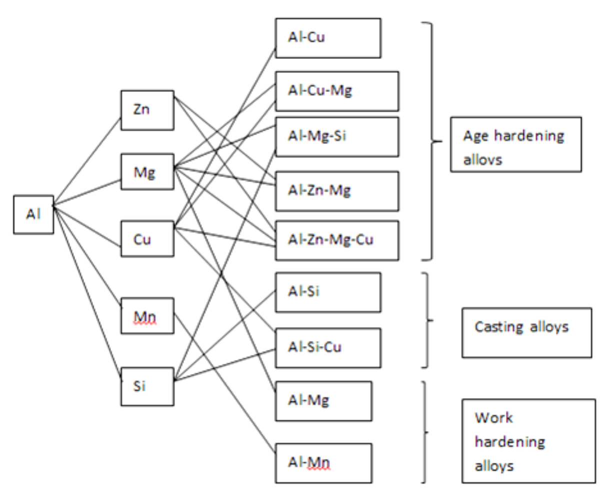


Figure 1. Major aluminum alloy system

2. Experimental Details

2.1 Precipitation Hardening/Age Hardening Treatment

An aging study was carried out on specimens of plain AA6061 matrix alloy and GCI reinforced AA6061 composite in order to find the time necessary to achieve peak hardness. The aging process involved solution treatment of the sample for 2 h at 550^{0}C, then quenching in water followed by artificial aging at 160^{0}C for different aging times.

2.2 Microstructure Studies

The majority of burrs on the specimen surface were removed by a belt polisher. The emery is initially used to polish specimens before polishing by disc polisher covered with velvet cloth. The alumina paste is also used during polishing so that mirror surface is obtained at the end of process. The specimens are further cleaned with water and dried using ethanol solution. Dried specimens are further etched with Nital, washed and dried after exposing for optimum duration with etchant. Inverted metallurgical microscope is used to capture the images of microstructure at 200X.

Table 2. Composition of AA6061 matrix material

Material	Si	Fe	Cu	Zn	Mg	Cr	Al
Wt%	0.60	0.50	0.23	0.20	0.98	0.23	Rest

2.3 Details of Hardness Test

The chemical elements of AA6061-T6 alloy used in this study is identified by spectral analysis and is given in Table 2. The specimens then subjected to heat treatment by retaining at 550^{0}C for 2 h followed by quenching in water at room temperature. The samples were artificially aged in the furnace at 160^{0}C for various time durations.

According to the Al-Mg-Si phase diagram melting of ternary eutectic Mg_2Si-(Al)-(Mg) phase takes place at 558^{0}C. It is reported that the samples of 6061 Al/SiC composite, with the solution heat-treated at 558^{0}C, exhibit better strength compared to the samples solution treated at 530^{0}C after aging treatment[9].

Hardness values are measured at time interval of 30/60 minutes, to determine the peak aging time for that specific temperature. Hardness tests were done by a Brinell hardness tester with steel ball indenter of diameter 5mm and a load of 250 kgf (SAROJ Brinell Hardness Testing Machine, Model:-B/3000/00, Sl#13/06/08-India).

Brinell hardness tests were conducted on both AA6061alloy and composites. The results of test are given in Tables 3-6.

Table 5. Hardness values of AA6061+4% GCI composites aged at 160^{0}C for different aging times

SampleNo.	1	2	3	4	5	6	7	8	9	10
Aging Time (h)	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5
BHN (aged at 1600 C)	62.1	75.1	75.1	80.8	83.1	87.3	98.4	112.7	88.4	87.7

Table 3. Hardness values of AA6061 alloy aged at 160^{0}C for different aging times

Sample No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Aging Time (h)	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5
BHN (aged at 1600 C)	57.6	63.3	63.3	69.1	69.1	85.2	55.8	76.8	81.9	77.9	83.2	76.2	82.6	85.7	89.7	90.4	87.7	81.9

Table 4. Hardness values of AA6061+2% GCI composites aged at 160^{0}C for different aging times

SampleNo.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Aging Time (h)	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5
BHN (aged at 1600 C)	60	71.5	69.1	83.8	89.7	83.2	76.8	82.6	82.6	77.9	91.8	99.3	93.6	89

Table 6. Hardness values in both as cast and peak aged conditions

Condition	AA6061-BHN	AA6061+2%-BHN	AA6061+ 4%-BHN
As cast	55	67	72
Peak aged at 1600 C	90.4	99.3	112.7

2.4 Details of Tensile Test

The dumb bell shaped tensile test specimens were prepared as per IS: 2102–1989 for the tensile test. The gauge length and diameter were 25 mm and 6.4 mm respectively (Figure 2(a)). The tensile test was carried out in a tensometer which was computer integrated to generate the on line plot of load-vs-extension. A sample fractured tensile specimen of AA6061+2% is as shown in Figure 2(b). Table 7 shows tensile strength in both as cast and peak aged conditions.

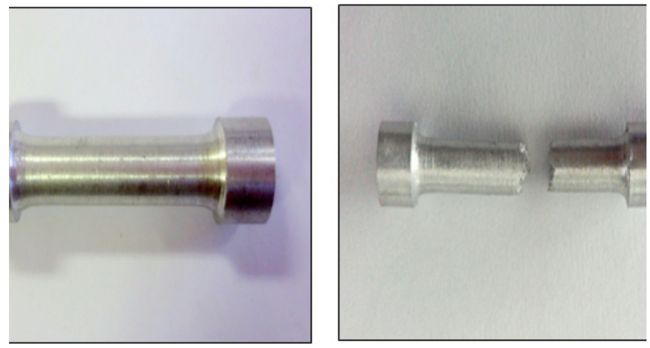
2.5 Details of Impact Test

The specimens were prepared as per IS: 1499–1959 for Charpy impact test. The total length was 55 mm of square cross section having dimensions 10 mm x10 mm. A U notch of 2mm width and 5mm deep was made at the mid length. Photographs in Figure 3 show the specimens prior and after impact test. Table 8 shows impact resistance in both as cast and peak aged conditions.

3. Results and Discussions

3.1 Micro-structural Features

Figure 4 shows the optical micrographs of AA6061 alloy, AA6061+2% GCI and AA6061+4% GCI reinforced composites respectively. Micrographs reveal that there is fairly uniform distribution of cast iron particulates throughout the matrix alloy and no porosity is found. Also, it can be observed that there is good bonding between the matrix and the reinforcement particulates resulting in better load transfer from the matrix to reinforced material. There was no agglomeration of reinforcements since sufficient care was taken to prevent agglomeration by preheating the particulates to 200^0C for 2 h.



(a) (b)

Figure 2. Tensile strength test specimen before (L) and after (R) the tensile strength test

Table 7. Tensile strength in both as cast and peak aged conditions

Condition	AA6061-MPa	AA6061+2%-MPa	AA6061+ 4%-MPa
As cast	84.2	102.6	110.2
Peak aged at 1600 C	137.2	149.5	171.3

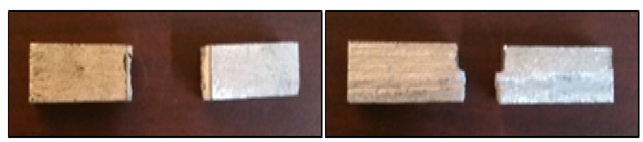


Figure 3. Charpy impact test specimen before (L) and after (R) the impact test

Table 8. Impact resistance in both as cast and peak aged conditions

Condition	AA6061-J	AA6061+2%-J	AA6061+ 4%-J
As cast	26	23	19
Peak aged at 1600 C	23	18	13

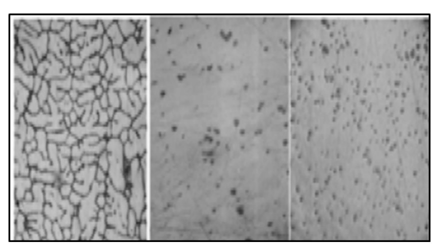


Figure 4. Micrographs in as cast conditions; AA6061 (L), AA6061+2% GCI (M) and AA6061+4% GCI(R)

3.2 Hardness

Figure 5 shows the hardness variation as a function of aging time for unreinforced AA6061 alloy,AA6061 +2% GCI and AA6061+4% GCI composites at 160^{0}C respectively. AA6061+4% GCI composite have achieved peak hardness at lesser duration as compared to bare alloy and composite with 2% GCI.

Figure 6 shows the comparison of hardness in as cast and peak aged conditions for a specific quantity of reinforcement. As seen from the plot that peak aged specimens may be in as cast or in composite form exhibited higher hardness compared to the casted counterparts.The cause for enhancement in hardness after solution treatment and subsequent aging can be attributed to the appearance of intermetallic precipitates. Solutionizing helps in homogenization of cast structure and reduces the segregation of alloying elements in the casting. Again hard GCI particles along with grain boundary will create more hindrances for motion of dislocations, and thus increasing the resistance to plastic deformation leading to greater hardness.

3.3 Tensile and Impact Test

As the weight % of the reinforcement increases the Ultimate Tensile Strength (UTS) value of the material increases in both as cast and peak aged conditions (Figure 7) due to increase in the hardness. Highest tensile strength is seen for composite specimen with 4% GCI. Also irrespective of whether bare alloy or composite, aging treatment brings improvement in UTS. Also the impact resistance is found to decrease with increase in the quantity of GCI in the alloy under as cast and peak aged conditions as depicted in Figure 8. The impact resistance is dependent on the ductility property. Since the ductility has reduced, impact resistance also lowered for the specimens.

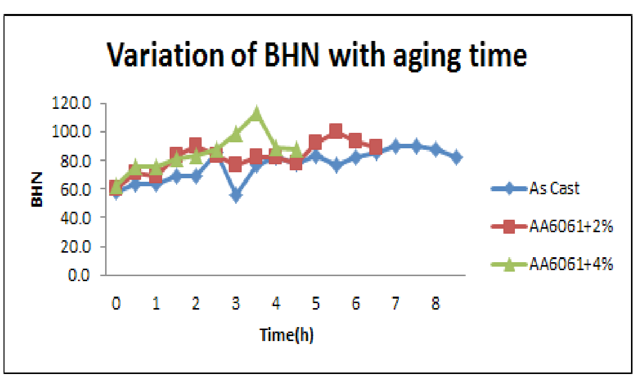


Figure 5. Variation of hardness values with time duration

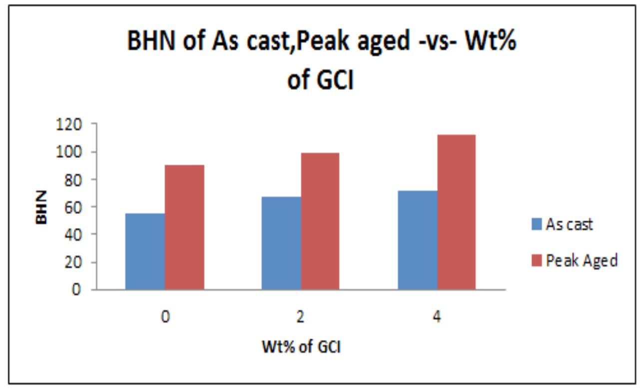


Figure 6. Comparison of hardness values in both as cast and peak aged conditions

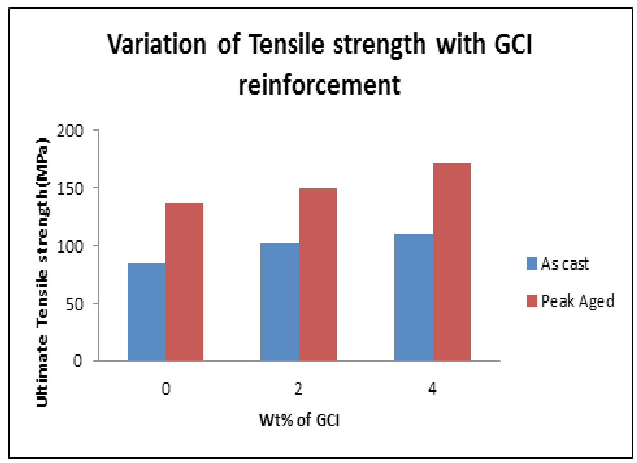


Figure 7. Comparison of UTS in both as cast and peak aged conditions

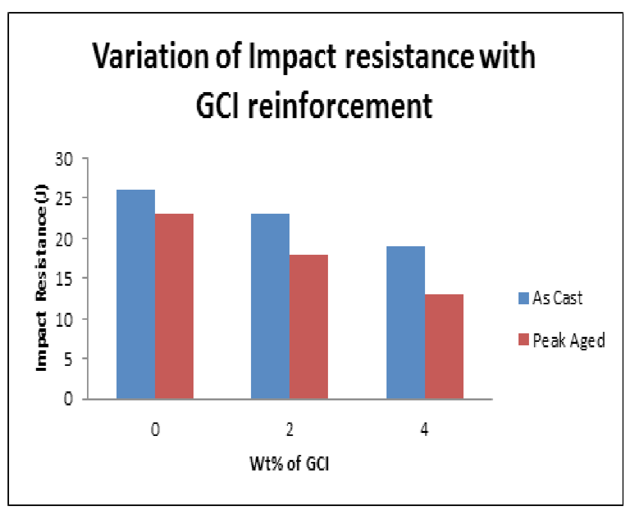


Figure 8. Comparison of impact resistance in both as cast and peak aged conditions

4. Conclusions

- Microstructure studies showed uniform distribution of Grey Cast Iron particulates in AA6061 matrix. The microstructure justifies that the stir casting process is one of the simplest and effective casting processes for particle reinforced MMC.
- Heat treatment gives positive effect on mechanical properties.
- Hardness has increased for composites compared to cast condition due to formation of inter-metallic precipitates.
- Tensile properties of cast and composite were improved due to heat treatment.
- Impact resistance is found to be decreasing as the quantity of reinforcement is increased in both cast and heat treated conditions because of loss of ductility.

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