Processing and Characterization of 6061 Aluminium Alloy with Nickel (Ni) and Zirconium (Zr)

S. Arun Kumar and R. Raman Goud

Abstract In an aluminium alloy, there are many inventions and researches that are introduced since 1954, when there are only 75 compositions are present, and by now, there are 530+ composites of aluminium. This explains how much we can explore aluminium with combinations of different alloys out of which 6061 aluminium alloy used for making automobile bodies. This experiment is to find the tribological behaviour of nickel (Ni), zirconium (Zr) particles reinforced with 6061 aluminium alloy. Composites are manufactured by a liquid metallurgical process known as stir casting. The alloy combinations constitute of 1. nickel (Ni)—0.5% and zirconium (Zr)—0.5%, 2. nickel (Ni)—0.5% and zirconium (Zr)—1% and 3. nickel (Ni)—0.5% and zirconium (Zr)—1.5% with 6061 aluminium alloy as a base metal. Above mentioned are three sample materials that are prepared by stir casting followed by annealing or heat treatment to improve the grain growth [1].

Keywords Metal matrix composite · Stir casting · Heat treatment · Tensile testing · Brinell hardness test

1 Introduction

In the current scenario, metal matrix composites are used in various engineering fields such as automobile, aerospace and structural applications etc., because of their high strength to weight ratio prevents oxidation and high stiffness. Aim of this experiment is to find the optimum weight percentage of the zirconium (Zr) added to the nickel (Ni) using 6061 aluminium alloy as base. Zirconium is a transition metal that has good resistance to corrosion and high melting temperature, which is used to improve the high-temperature tensile strength and hardness of the material. Nickel (Ni) is also a transition metal that is ductile in nature, hard and prevents oxidation, having the crystal structure as face-centred cubic structure. When nickel (Ni) and zirconium

S. Arun Kumar (✉) · R. Raman Goud
Department of Mechanical Engineering, Gokaraju Rangaraju Institute of Engineering and Technology, Hyderabad, Telangana, India
e-mail: arun4688@gmail.com

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Table 1 Chemical composition (wt%) of the 6061 aluminium alloy used in the study

Chemical component	Cr	Cu	Mg	Si	Al
Weight (%)	0.16	0.2	1.05	0.43	98.16

(Zr) combined together with 6061 aluminium alloy results in an increase in tensile strength at 1% of zirconium (Zr) and 0.5% of nickel (Ni) and decreases on further more increase in 1.5% of zirconium (Zr). In the experiment, it is known the role of zirconium (Zr) in the aluminium alloy and weight percentage of zirconium effects in the behaviour of the casted material [2, 3]. Addition of the nickel and zirconium increases the hot tensile strength and hardness [4].

1.1 Material

6061 Aluminium Alloy:

6061 aluminium alloy is a precipitate and hardened alloy containing magnesium and silicon as its major alloying elements. It is one of the most versatile of the heat-treatable alloys and popular for its range of strength application and requirements, it possesses good toughness and excellent prevent oxidation.

Typical applications of 6061 aluminium alloy are transportation components, aircraft and marine fittings, machine processing equipment, recreation products as shown in Table 1.

2 Experimental Method

2.1 Stir Casting

Stir casting is an economic process for the production of aluminium matrix compounds. The process consists of a small crucible placed in a furnace [5, 6, 7]. Before the addition of the material into the furnace, the raw materials have to be weighed and calculated according to the composition of 6061 aluminium alloy with the following compositions 1. nickel (Ni)—0.5% and zirconium (Zr)—0.5%, 2. nickel (Ni)—0.5% and zirconium (Zr)—1% and 3. nickel (Ni)—0.5% and zirconium (Zr)—1.5%. The optimum amount of raw 6061 aluminium alloy is heated up to the melting point of 800 °C [8, 9, 10]. When the furnace reached up to the melting temperature, the motor-powered stirrer rotates resulting in better mixture of alloy. The stirring process has to continue for 5 min. After mixing, the composite in a molten state is poured into a fixed die, followed by a cooling process. The resultant composite will be in a form of flat plate (Fig. 1).

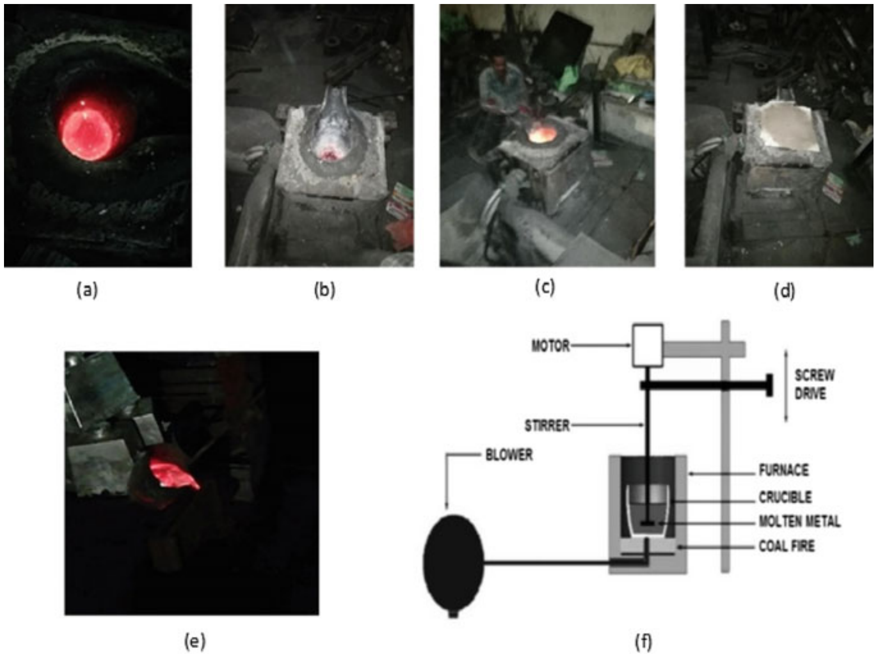


Fig. 1 **a**, **b**, **c** Melting of aluminium alloy, **d** adding nickel and zirconium, **e** pouring molten metal into fixed die, **f** Stir casting process

2.2 Annealing Process

Annealing or heat treatment is employed to improve the mechanical properties, grain size of the resultant composite. 475 °C is the optimum temperature for aluminium alloy for grain growth, better mechanical properties and zirconium dispersoids in resultant composite [11]. The casted specimens were subjected to 475 °C in furnace for 15 h and quenched, so that the nickel and zirconium fill the voids within the resultant composite and followed by heat treatment at 475 °C for 2 h again, so that the resultant composite improves mechanical properties.

3 Experimental Procedure

3.1 Tensile Testing

Tensile strength of a material is an important characteristic of a material it is useful to define elastic–plastic behaviour of a material by applying the tensile load on the material, specimens are made from the casted material 3 sample pieces from each casted plates and machined to standard specimen of ASTM E8 tensile test samples are made in types of plates [12] and the sample pieces are tested to know the characteristics of the aluminium alloy by Universal Tensile Testing Machine (UTM) (Fig. 2).

The sample specimens are prepared for tensile test as per ASME E8 [13, 14] tensile test by milling operation as shown in Figs. 3 and 4.

The specimens are subjected to tensile load on UTM for obtaining the stress and strain diagram and yield strength of the composition prepared by stir casting and heat treatment process.

Fig. 2 Universal testing machine (UTM)

Fig. 3 Test sample before tensile test

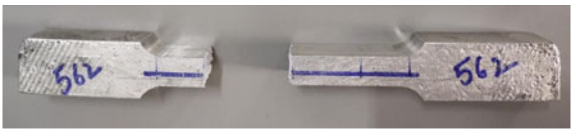


Fig. 4 Test sample after tensile test

Fig. 5 Brinell hardness testing machine

3.2 Hardness Test

Hardness is an important property of the material, it defines the ability to resist the indentation or scratch over the surface of the material, it can be obtained from hardness testing methods such as Brinell hardness test, Vickers hardness test and Rockwell hardness test, to find the hardness of the material, a fixed force is applied to a given ball in case of Brinell hardness test and diamond in case of Vickers hardness test. When the indentation is small, then the material hardness is more, when the indentation is large, then the material hardness is less [15] (Fig. 5).

The hardness of aluminium alloy material 6061 aluminium alloy with nickel and zirconium alloy material is measured using Brinell hardness Testing (BHT) equipment. The load was applied for finding the hardness at 5 points and these will give the average hardness of the Al Ni and Zr compositions.

4 Results and Discussion

Stir Casting:

In stir casting, aluminium alloy is molten and stirred at 800 °C and then it is poured into the die to solidify, the pouring temperature is 780 °C, zirconium (Zr), nickel (Ni) are added to 6061 aluminium alloy at 800 °C and stirred for 20 min. The molten 6061 aluminium alloy, nickel 0.5% and zirconium 0.5, 1 and 1.5% alloy are poured in fixed dies to make a shape of material into plates. The material is made in the shape of plate and chemical test is made for the alloys containing aluminium nickel and zirconium composition. The following Table 2 shows the combination of different materials in the alloys prepared.

Tensile test:

Tensile test is conducted to characterize the elastic and plastic behaviours of prepared material by applying uniaxial tensile load. The test is performed on the test samples made as per the ASTM E8 standard. The tensile test provides the results of the following parameters: yield strength, tensile strength, elastic modulus, Poisson's ratio and elongation. 6061 aluminium alloy, nickel and zirconium fabricated using stir casting are cut into standard dimensions as per the ASTM E-8 standard by machining. The tensile test samples were mounted onto the universal testing machine and hold steadily using grippers. Force was applied using a hydraulic system to stretch the tensile component until it fails. The localized strain variations in the tensile samples were measured using extensometer in terms of load versus displacement curve. Engineering stress–strain relation was calculated for each specimen. The results are presented in Table 3.

Hardness:

The material hardness is measured using Brinell hardness tester BHN (BV 250 Spl) at a load of 250 kg applied for a duration of 10 s at five different locations on all

Table 2 Chemical composition (wt%) of the Al alloy made by stir casting in experiment

Sample No.	Cr	Cu	Mg	Si	Ni	Zr	Al
1.	0.16	0.27	1.05	0.36	0.51	0.52	97.13
2.	0.16	0.20	1.07	0.41	0.53	1.06	96.57
3.	0.16	0.22	1.02	0.39	0.54	1.57	96.1

Table 3 Characterization of the prepared aluminium alloy sample specimen

Sl. No.	Sample	Tensile strength in MPa	Yield stress in MPa	Hardness in HBW	Elongation (%)
1.	Al, Ni-0.5%, Zr-0.5%	126.455	99.43	64.9	3.12
2.	Al, Ni-0.5%, Zr-1%	218.86	174.41	85	3.14
3.	Al, Ni-0.5%, Zr-1.5%	77.443	58.146	55.7	2.26

samples. The hardness of the material is increased at 1% of Zr in aluminium alloy, and hardens is decreased when further more increase in Zr in alloy, which is seen at 1.5% Zr alloy.

$$\text{BHN} = \frac{2F}{\pi D\left[D - \sqrt{D^2 - d^2}\right]}$$

where,

BHN	Brinell hardness number
F	Force applied on the work
D	Diameter of ball
d	Diameter of indentation.

Below figures represent the variation in the tensile strength and hardness for the samples for the experiment readings (Fig. 6).

The above figure shows the increasing trend of the tensile strength of the alloy as Ni and Zr at 0.5% and 1%, respectively, and further more increase in Zr leads to a drastic decrease in tensile strength (Figs. 7 and 8).

Fig. 6 Tensile strength variation with samples

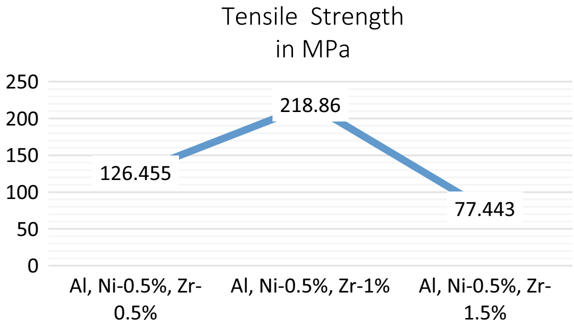


Fig. 7 Percentage of elongation of resultant components

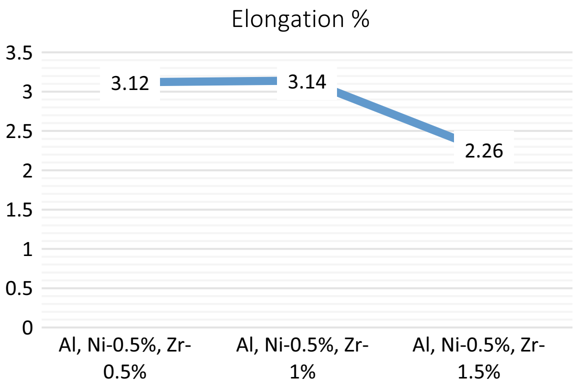
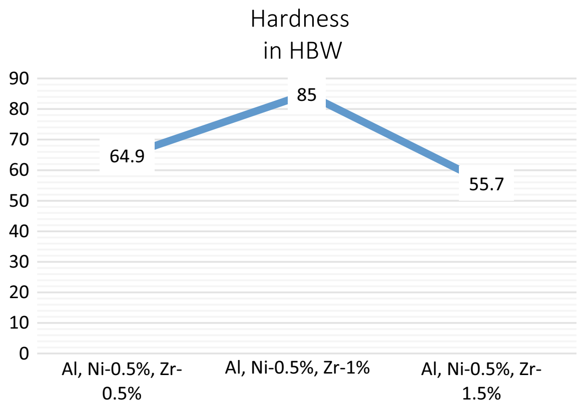


Fig. 8 Hardness of the resultant components



The above figure shows that the increasing trend of the hardness of the alloy as Ni and Zr at 0.5% and 1%, respectively, and further more increase in Zr leads to a drastic decrease in hardness.

5 Conclusion

The preparation and characterization of aluminium 6061 with nickel and zirconium were experimentally investigated. At the end of the work, the following conclusions are obtained:

1. Stir casting of the aluminium with nickel and zirconium alloy is prepared successfully at the temperature 800 °C.
2. Heat treatment or annealing process of the casting material for 15 h [11] improved the material mechanical properties and machining ability.
3. By increasing percentage of zirconium (Zr) in the 6061 aluminium and 0.5% nickel (Ni) alloy, there were changes observed in the material. The zirconium (Zr) per cent was added, 0.5, 1 and 1.5% were added to the material, the strength and hardness were improved at 0.5% zirconium (Zr) and 1% zirconium (Zr), and then further increase in zirconium to 1.5%, then tensile strength and hardness are showing decrease in trend.
4. Hardness is more at 1% of zirconium (Zr), 0.5% nickel (Ni) in 6061 aluminium alloy.
5. Tensile strength is maximum at 1% of zirconium (Zr), 0.5% nickel (Ni) in 6061 aluminium alloy.

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