Augmented mechanical properties of magnesium AZ91 reinforced with graphene

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Abstract. Graphene has been impressing us in recent years by boasting some very spectacular things. Its outstanding mechanical properties made the material to be used in composites for amplifying the strength. Mechanical properties usually take precedence for magnesium alloy when it would be used as a structure material. The main focus of this project is to manufacture magnesium reinforced metal matrix composites using graphene nano powder through stir casting to enhance the mechanical properties. The uniform distribution of graphene nano powder and its large specific surface area per volume is embedded in magnesium matrix leads to increase in micro hardness, tensile solidity, fracture exertion of the composite. Compared with standard single crystal magnesium, the Mg AZ91 with 0.3 and 0.7 wt % graphene nano powder composite indicates improvement in mechanical properties. In addition to standard procedures for the tests and dissection of mechanical properties of synthesized composite, dewinter invertor trinocular metallurgical microscopy, is used to investigate the phase segmentation, grain size and phase contrast. Additionally, Mechanical properties of synthesized composites of two different composition of graphene were compared.

Keywords. Nano Powder; Monolithic magnesium; metal matrix composite; phase segmentation

1. Introduction
Composites have played a crucial activity all through the evolution, from building houses in early civilizations to empowering future innovations [1-12]. It's a mix of two materials with different physical and chemical properties. they're combined to make a cloth specialized to try and do a particular job, for instance, to become stronger, lighter, or immune to electricity. the key points among many benefits of composites are design flexibility, corrosion resistance, lightweight, strength, and durability [13-22]. The objective of this work is to infuse graphene with magnesium reinforced metal matrix composites via stir casting to enhance the mechanical properties and compare Mg AZ91 of two different compositions of graphene. Compared to pure magnesium and other alloys of magnesium, the Mg AZ91 with 0.3 and 0.7 wt % graphene nano powder composite indicated the improved modulus, hardness, yield and ultimate tensile strength.
2. Experiment Details

2.1 Experimental Process
The experimental setup has been connected to the gear-box motor and mild steel quad-blade stirrer. The liquefying of the Magnesium AZ91 and GNP's powder (320 grit size) is carried out in the furnace. Initially the Magnesium AZ91 and GNP's were heated for 1 hour at 870-900°C and then mixed with each other below their melting points mechanically. The furnace temperature was started increasing above the composites saturation and completely melt the scraps of magnesium and then cooled down well below the component temperature to be kept in a semi-solid state. At this state graphene nano powder added and manually mixed with each other. It is more complex to mix it by machine or stirrer when MMC are in semi molten state commonly takes place with manual mixing taking place. Once the manual mixing is completed then stirring will be carried out automatically for minimum of ten minutes with normal 400 rpm of stirring rate and the rate of temperature of the furnace should be controlled at 890°C at the end mixing process. After the completion of process the slurry must be removed from the mold and within thirty seconds allow it to solidify followed by vicker’s and impact tests should be taken from the solidified samples. This experiment should be repeatedly conduct by various compositions of the GNP's (0.3% and 0.7%), weight of Mg AZ91 in grams.

![Figure 1. Flow Process of Stir Casting](image1.png)

**Figure 1.** Flow Process of Stir Casting

![Figure 2. Stir Casting.](image2.png)

**Figure 2.** Stir Casting.
2.2 Machining Process

The Mg-GNPs composite obtained is the machined and cut down according to the requirement. For tensile test, a sample of dimensions 120mm length and 15mm width which is tapered inward at the middle of width 10mm. For Izod impact test, a sample of dimension 60mm length and 15mm width with V-Groove at the center is cut out and machined. For Micro-structure, hardness test, a sample of dimensions 15*15mm small cube is cut out and machined. The machining process was carried out for the required size of specimen for different testing methods using : UTM-Universal Testing Machine, Izod Impact testing and Vickers Hardness Testing. Based on the specifications of the machines the specimen sizes will be obtained by the machining process. The specimen sizes follows:

![Figure 3. Mg-Gr composite before machining](image1)

![Figure 4. Mg-Gr composite after machining](image2)

The specimen size we have taken for tensile test was of total length 120mm and grip section width of 15mm with reduced section of length 60mm and gauge length 40mm. The specimen size we have taken for Izod impact test was of overall length 60mm and width of 15mm with a notch 45° notch, 3mm deep at the center.

3. Results and Discussion

3.1. Micro-structure

Sample No: 1 AZ91 with 0.7 wt % of graphene composite stir casting
Magnification: 100X and 200X
Etchant: Picral+ Hydrogen peroxide+ Acetic acid

![Figure 5. Micro-structure of AZ91 with 0.7 wt% of Graphene](image3)
In above figure 5 showing the micro-structure of the Magnesium alloy AZ91 stir cast with addition of graphene composite particles. The micro-structure details of the inter-dendritic fine grains of magnesium with precipitated eutectic particles of Al12 Mg17 at the grain boundaries. The metal structure displays the disposition of infinitesimal particles of graphene at the grain boundaries.

Similarly in figure 6 which present to view the sample that has been resolved the grain boundaries and confined corpuscle of Graphene composite corpuscle visible in black color and at the grain boundaries. The corpuscle of composite are finer and hence trapped along the grain boundary junctions. The distribution of the composite corpuscles is uniform.

**Sample No 2: AZ91 with 0.3 wt% of graphene composite stir casting**

Magnification: 100X and 200X
Etchant: Picral+ Hydrogen peroxide+ Acetic acid

Alike the above analogy Figure 6 also shows the micro-structure of the Magnesium alloy AZ91 stir cast with addition of graphene composite corpuscle. The micro-structure shows infinitesimal inter dendritic fine grains of primitive Magnesium with precipitated eutectic particles at the grain boundaries. The metal matrix also visualizes the disposition of fine corpuscle of graphene at the grain boundaries. The grains are fine and their grain size is 40 microns. Also the figure shows the identical sample which has dissolved the grain boundaries and confined corpuscle of composite along the grain boundaries. Few blocks of composite corpuscle have shows cavities and pores in the metal-matrix.
The sum of track elements could come down in magnesium as fine corpuscle. Photo-2 shows group of composite corpuscle occupies the intersection of the grain boundaries of magnesium.

3.2. Tensile Test

**Sample No: 1 AZ91 with 0.7 wt % of graphene composite stir casting**

The graph figure 7 shows that the specimen can withstand the tensile load of 1.75 kN and a maximum displacement of 1.11mm. So, the maximum tensile robustness of the specimen is about 1420 MPa which is elevated compared to the tensile solidity of Mg AZ91 (230-250 MPa). The maximum elongation % of the specimen is about 0.33. This graph of figure 8 gives the analogs of stress-strain. This is acquired by gradual application of the load to a test coup and observing the change in shape, from this stress-strain can be studied. The Maximum stress was nearly 62.08 MPa and maximum strain is up to 3.7%.

![Figure 7. Load vs Displacement Graph](image1)

![Figure 8. Stress vs Strain Graph](image2)

**Sample No 2: AZ91 with 0.3 wt% of graphene composite stir casting**

![Figure 9. Load vs Displacement Graph](image3)

![Figure 10. Stress vs Strain Graph](image4)
The graph figure 9 shows that the specimen can resist the maximum tensile load of 3.28 kN and a maximum displacement of 2.31 mm. So, the maximum tensile strength of the specimen is about 614 MPa which is also slightly high compared to the tensile strength of Mg AZ91 (230-250 MPa). The maximum % elongation of the specimen is about 0.4. Also, the graph from figure 10 gives the inter-relation between stress-strain. It is acquired by gradual application of the load to a test coup and again observes the deviation, from which the stress-strain can be studied. The Maximum stress was nearly 116.35 MPa and maximum strain is up to 7.7%.

4. Conclusion
Magnesium metal matrix composites reinforced with Graphene nano powder is prepared by stir casting method. From the tests taken on the specimens of Magnesium AZ91 with two different compositions of graphene, we can conclude that the specimen with the higher graphene composition have better tensile strength, good toughness and hardness. Also, we can clearly see that if the composition of graphene increases, the mechanical properties of the Magnesium AZ91 gets drastically changed in positive note. The main barrier is that the magnesium and magnesium alloys is flammable. As a further step in this project, we are planning to remove this barrier by adding Cadmium at a specific ratio to this composite.

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