Investigation of aluminium LM6 metal matrix composites reinforced with graphene flakes using stir casting process

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Abstract. Through the past decades Aluminium has been used in several manufacturing sectors because of its unique properties like light weight, highly malleable and ductile, high strength etc. Metal Matrix Composite (MMC) is being in trend due to its ability to inhibit good properties of its constituents. The purpose of this paper is to manufacture Aluminium LM6 MMC with infused Graphene Flakes (in concentration of 0.1%, 0.25%, 0.4% by weight) by Stir Casting Process and to study the changes in the mechanical characteristics and compare with the former. Secondly as Graphene is highly expensive material we will be using Exfoliation method to extract Graphene Flakes from the graphite rods.

1. Introduction

Today in the modern industries Aluminium is the most important engineering metal and is used in various engineering fields such as the automotive, aerospace industries etc because of their outstanding properties namely, high specific strength, high wear resistances, high stiffness, high dimensional stability, high corrosion resistance and light weight product. [1-2]. Since late eighty this has become the most researched field topic to increase the strength of the Aluminium metal without compromising its ductility and its always been a challenge to the scientist. Aluminium metal matrix composite (hybrid aluminium matrix) became an important research work conducted by many people. In Aluminium matrix composite aluminium of serves as the parent material and an reinforcement is added with it in specific measurements to boost up its mechanical properties, there are many researchers trying out different materials as reinforcement to get the desired output, as each reinforcement produces a different set of material properties.[4-5]. Commonly carbides of transition metals or non-metals like silicon carbide(SiC), Tungsten carbide(WC), Titanium Carbide(TiC) or simply the non-metals that tend to increase the bonding strength are used as reinforcement. Generally hybrid aluminium composites are manufactured by various process like powder metallurgy, melting and squeeze casting stir casting, powder metallurgy and heat sintering etc[7]. Generally powder metallurgy and cryomilling techniques are used to achieve uniform mixing of the reinforcement with the base material followed by sintering to strengthen the bonding and to reduce the void the lattice structure. Graphene an allotrope of carbon with single layered one atom thick lattice structure with sp² hybridisation[11], it has been an intensive research material due to its high electron mobility of 15000 cm²/(V.s) and its approximately 10 times higher than the normal semiconductor wafer, being a single layered structure it has a low density of 2.2 g/cm³, extremely high thermal conductivity 3000 W/(m.K), high electrical conductivity, and although being a non-metallic compound it has high tensile strength reaching up to 1060 GPa and its one of the hardest material besides diamond[10]. These splendiferous properties of graphene makes it the most expedient reinforcement with several base material alloys. Muhammet et al. [12] investigated on the hot extruded pure aluminium matrix composite with reinforcement as single dimensional multi-wall carbon nanotube and two-dimensional graphene nanoplatelets(GNP), according to his research theory there was an substantial increase in the mechanical properties of the pure aluminium when reinforced with the graphene and also inferred that there was no formation Al₄C₃ compound during the x-ray diffraction
analysis. Sreehari Peddavarapu et al. [13] they investigated the tribological properties of the aluminium 6082 with graphene nanoflakes as reinforcement using the stir casting machine, they tested the samples using a Pin-on Disc tribometer to determine the wear properties at different velocity and load conditions. According to them there was a quite improvement in the wear loss properties and heat generation compared to non-reinforced aluminium alloy and it was due to the lubricating properties of the graphene that the wear was reduced to a significant amount. Ajay Kumar P et al.[14] they reinforced graphene nanoflakes with the aluminium A356 using friction stir casting machine and investigated the mechanical properties like tensile strength, elongation, hardness test, and performed Transmission Electron Microscopy(TEM), fractography analysis and XRD analysis. After the experimentation they inferred that the after the friction stir casting the TEM analysis showed that the graphene was encapsulated in aluminium matrix and there were reduction the voids and defects between the graphene and aluminium, then there was 12% increase in the ductility of the reinforced aluminium matrix, the grain size was reduced and work hardening rate was increased. Mohammad Khoshghadam-Pireyousefan et al.[15] investigated on the advanced method of producing aluminium graphene reinforced matrix incorporating high energy ball mill and molecular level mixing and followed by spark plasma sintering, they inferred the manufacturing of uniform distribution of Cu nanoparticle with graphene oxide nanosheets and there was no traces of $\text{Al}_2\text{C}_3$ during the XRD analysis, secondly the $\text{Al}_2\text{Cu}$ particles were precipitated homogenously after the spark powder sintering and there was around 78% increase in the yield strength of the composite thus formed. Yu Zhang Ng et al.[16] they performed an investigatory experiment on the process of electrochemical exfoliation of graphene with an stabilizer like diethanolamine(DEA) and the structural properties were analysed by performing FESEM, Raman spectrometer. The Liquid-phase exfoliation enforced with electrochemical process and constant current setup produced uniform graphene sheet by alleviating the heat absorption by the graphene nanoflakes, it was also inferred that with the addition of the stabilizer there was agglomeration of graphene flakes and thus resulting in non-uniform sheets compared to the one formed without the use of stabilizer. From the literature so far done it is observed that most of the experimental analysis using the graphene nanoflakes as reinforcement are done on the wrought aluminium alloys with low silicon content. For our experimental and investigation work the Stir Casting machine was used for preparing the Aluminium LM6 samples with 0.1, 0.25 and 0.4 wt% of graphene as reinforcement. The main idea behind using the casting alloy is to mainly observe the effect of graphene reinforcement in the presence of silicon as the second major constituent of the alloy. The Graphene flakes are generally produced by various industrial methods for instance electrochemical exfoliation of the graphite sheets or rods, or by the reduction of graphene oxide in colloidal solution via chemical reaction called Hummers Reaction. We adopted the method of electrochemical exfoliation, in this process high voltage is passed across the graphite films with zinc sulphate as electrolyte slow dissociation of the carbon atoms form the graphite rod produces 3-5 layered stacked carbon atoms which on further processing through ultrasonicator yields graphene nanoflakes. These graphene flakes are majorly used to fabricate graphene layered composite, hybrid Aluminium composites and metal matrix composites[6]. The crucial task is to carefully diffuse the graphene flakes with the Aluminium metal so to provide required mechanical strength without inhibiting the brittle behaviour to the metal composite thus produced. The mechanical properties are determined by the uniformity and diffusion of the graphene flakes in the Aluminium matrix. This research investigation mainly focused on the effect of mechanical and materialistic properties of casting Aluminium LM6 casting alloys with graphene flake reinforcement as it contains 10-13% silicon, secondly there was a major challenge to dominate the mechanical strength over the brittle behaviour and to observe the microstructure of the Aluminium composite using field emission scanning electron microscope(FESEM) with electronic discharge spectroscopy(EDS).

2. Materials And Methods

2.1. Properties of Materials
For the investigation purpose we decided to use casting aluminium alloys. Cast Aluminium alloys mostly constitutes of the Al-Si matrix, they are used in every manufacturing industry for the casting purpose because of their high mechanical strength, ease in casting process, better weldability, corrosion
resistant. Among the various casting alloys we choose the LM6 alloy as its commercially used for casting and its cost-effective. LM6 alloys are generally used in automotive industries, aerospace industries and marine applications.

**Table 1. Material Properties of the LM6 alloy[18]**

| Material Properties       | Properties        |
|---------------------------|-------------------|
| Density                   | 2650 Kg/m³        |
| Thermal Conductivity      | 0.34 cal/cm²/°C   |
| Tensile Strength          | 170-180 N/mm²     |
| Elongation(in %)          | 7                 |
| Brinell Hardness          | 55-60             |
| Elastic Modulus           | 71                |
| Impact Strength           | 9.0 N-m           |

**Table 2. Percentage of constituents present in the Aluminium LM6 alloy**

| CONSTITUENT       | PERCENTAGE |
|-------------------|------------|
| Silicon           | 12.92%     |
| Copper            | 0.66%      |
| Iron              | 0.23%      |
| Zinc              | 0.10%      |
| Magnesium         | 1.71%      |
| Tin               | 0.11%      |
| Titanium          | 0.04%      |
| Vanadium          | 0.02%      |
| Polonium          | 0.09%      |
| Nickel            | 0.32%      |
| Manganese         | 0.20%      |
| Aluminium         | 83.53%     |

**2.2. Stir Casting Process**

Stir casting is the most economical and widely used commercial method for the manufacturing of Aluminium Matrix Composite or hybrid Aluminium matrix composites. It’s also classified as the liquid state method of composite material fabrications. Generally Aluminium metal is placed in a ceramic crucible and is heated to temperature of 800°C - 900°C i.e. just above the melting point of the Aluminium. Then the required reinforcement is added to the molten metal and with the help of the mechanical stirrer set at the required rpm is used to properly mix the reinforcement with the liquid metal. This technique is also referred to as Vortex technique that creates a small vortex so that the reinforcement can uniformly dispersed into the molten metal. The stir casting process is limited to certain amount of dispersion and there is not complete homogeneity. There are chances that the reinforcement particles might settle at the bottom or form clusters due to difference in the densities and gravity. Although there are some drawbacks of stir casting machine it’s still used for mass production of AMC and MMC. In our setup, we have placed the LM6 ingot inside the furnace, as per its dimensions. Then the machine is switched on and the temperature is raised to 897°C. During melting, the molten aluminium will react with the atmosphere to form a layer of aluminium oxide which will shield the surface from further reaction with the atmosphere. The metal mould is placed in an oven to be heated to about 450°C, so that when we pour the molten metal into the metal, the possibility of bubble formation is reduced. The
graphene flakes are then placed inside a granite cup and heated to 200°C. After the matrix metal have completely melted, graphene flakes is slowly dispersed into the molten matrix metal. Instantly, the stirrer is brought down via a remote and placed in position inside the furnace. The stirrer is turned on with a RPM of 334 which will enable uniform dispersion of reinforcement. Degassifier powder was dispersed into the molten metal, while the stirrer is still active. Wetting agents like borax and magnesium are added so that the formation of aluminium oxide does not take place, as Al2O3 will prevent the uniform mixture of graphene particles and the matrix metal. After 4 minutes, the metal is poured into the mould (which is to be removed when the metal is ready to be poured).

![Figure 1. Stir casting machine](image)

2.3. Graphene Preparation

There are various industrial methods to produce graphene nanoflakes like chemical vapor deposition(CVD), mechanical and thermal exfoliation process, Hummer’s method that basically involves the catalytic reduction of Graphene Oxide. Prashant Tripathi et al.[17] investigated on the process of electrochemical exfoliation of the graphene using graphite rods in an alkaline electrolytic solution and analyzed the graphene sample thus produced using TEM images and HRTEM micrographs, according to them by applying the DC bias voltage across the platinum and graphite electrode the kinetics of the reaction were enhanced and produced 1-4 layered graphene sheets. In depth study of the electrochemical exfoliation we decided to proceed with this method. In our experimental setup graphite rods are connected to positive and negative terminal and then a high DC voltage is applied. The setup is placed in an acidic electrolytic medium (0.5M Na2SO4 solution). The graphite rod in the presence of sulphate ions reduced to lesser stacked graphene sheets losing electrons. The graphene produced through the exfoliation process is further processed under ultrasonic sonicator to break the graphene stacks to 1-4 layered structures. The process continued for two days and the electrolyte was periodically changed so to stabilize the kinetics of electrochemical electrolysis. The solution is filtered out using filter paper and the graphene sample is cleansed and sterilized with the conc. HCl to ensure there is no impurities left out. Graphene sample is mixed with acetone solution and is placed in a ultrasound machine for couple of time and is operated at frequency of 40KHz. Then solution is again filtered to accrue the graphene sample and dried in a furnace at 120°C.
2.4 Aluminium Sample Preparation
This task was done with the help of Stir Casting machine as mentioned earlier because of its simplicity and less time consumption its best suited for Aluminium Matrix composite fabrications. The Aluminium we used was casting Aluminium (LM6 alloy) generally used for casting purpose. The alloy was first cut into billets of 1 kg each and then preheated in crucible in the Stir Casting machine for three hours so that the metal gets completely liquified. We made three Aluminium samples with varying concentration of graphene powder(0.1%, 0.25% and 0.4% wt.). The graphene powder was also preheated and then mixed with the molten metal, degasifier agent was also added to the molten metal so that the trapped gases can escaped out. The uniform mixing was achieved with the help of mechanical stirrer that was rotated at 400 rpm for 15 minutes. Then the molten metal with reinforcement was poured in the heated metal die to get a cylindrical cast and was left aside to get solidified. The cast was then machined out to get a test specimen for Tensile Test, Charpy Test, Brinell Hardness Test and for observing the microstructure of the metal composite.

3. Results And Discussion
The mechanical properties of the Aluminium LM6 alloy with varying concentration of graphene nanoflakes as reinforcement(0.1,0.25,0.4 wt%) are analysed by performing Tensile strength, Brinell Hardness Test, Impact Test. The morphological of the matrix formed was determined from the results obtained by FESEM (Field Emission Scanning Electron Microscope) and the spectroscopy report from the XRD. The data has been presented with brief discussion in the following section.

3.1. Tensile Test
The mechanical properties of cast samples such as tensile strength was determined using the UTM(Universal Testing Machine)[8]. The tensile tests were conducted on tension test specimens of dumbbell shape with the gauge thickness of 10mm and length 45mm and the total length of sample 75mm and outer diameter 20mm. During tensile test, a sample is subjected to controlled tension until it attains failure. we can find the ultimate tensile strength, maximum elongation, reduction area and various other properties from this test. For an isotropic material, uniaxial tensile testing machine is the most used. This test is conducted to find a suitable material which will perform under normal and extreme forces. A tensile specimen is generally a standard piece, with 2 shoulders and a gage, where the shoulders are used so that they can be readily gripped, and the gage section is where the deformation occurs.
Table 3. presents the data obtained by the Tensile Test of the Aluminium graphene metal matrix sample with 0.1, 0.25 and 0.4% wt reinforcement of graphene and the base aluminium LM6 alloy.

| Sample Prepared                      | Ultimate tensile strength |
|--------------------------------------|---------------------------|
| LM6 alloy without graphene reinforcement | 175MPA                    |
| 0.4% graphene                        | 190MPA                    |
| 0.25% graphene                       | 217MPA                    |
| 0.1% graphene                        | 246MPA                    |

Analysing the results obtained it can be inferred that there is a increase in the tensile strength of the LM6 metal matrix infused with 0.1%wt graphene, subsequently with further increase in the percentage of Graphene reinforcement there was a gradual decrease in the strength of the metal matrix. This decrease in the tensile strength with increase in the graphene reinforcement is due to the dominance of the brittle nature of the Graphene over the Al-Si dominating matrix properties. It can also be inferred from the results that around 0.1% there was a maximum increase in the tensile strength so the reinforcement ratio should be maintained in the range of 99.9% base metal and 0.1% approx. Graphene reinforcement. Apart from the Tensile strength the brittle nature of the matrix alloy was confirmed by the fracture pattern, surface finish of the crack and necking process, it was observed that the sample broke at an instant without undergoing a gradual necking process. It can be stated based on the spectroscopy report of the compound that there might the possibility of formation of the Si-C compound due to excess amount of Silicon present in the alloy mixture this in turn adds to the brittle nature of the matrix thus formed. The figure 11 shows the graph obtained after the tensile strength testing of the samples.

Figure 5. Graph of Engineering Stress vs Strain (a) 0.1 wt% of graphene reinforcements. (b) 0.25 wt% of graphene reinforcements. (c) 0.4 wt% graphene reinforcements
Figure 6: Graph comparing the tensile strength for (a) LM6 alloy without reinforcement (b) 0.1 wt% of graphene reinforcement (c) 0.25% wt% of graphene reinforcement (d) 0.4 wt% of graphene reinforcement

The graph above shows the tensile strength of the composite materials manufactured. As per this graph it can be implied that the strength of the material increased when doped with 0.1 percent of graphene and while increasing the concentration, the strength is shown to be decreasing.

3.2. Impact Test
Impact testing were done using the Charpy Impact Testing Apparatus and amount of energy absorbed by the material during a fracture (impact) and the nature of fracture were obtained. The test samples after the testing are shown below with the crack pattern. Samples were prepared as per ASTM: D256 Standard. An arm of the machine is held at the specified height (with constant potential energy) and released so it hits the sample, the sample absorbs certain amount of energy which is then noted. Impact test was the only possible test to prove that with the reinforcement of graphene and silicon in the Aluminium base metal introduced the brittle nature and after certain concentration limit the brittle nature surpassed the ductile behaviour of the metal and made it to lose its ductility. The figure 7 shows the Impact strength samples after the experiment and from the crack pattern the brittle nature of the matrix can be inferred.

Figure 7. Charpy test sample for 0.4 wt.% graphene reinforcement
Figure 8. Charpy test sample for 0.25 wt.% graphene reinforcement
Figure 9. Charpy test sample for 0.1 wt.% graphene reinforcement
The Table 4. Below shows the Impact force sustained by the Aluminium graphene metal matrix sample with 0.1, 0.25 and 0.4% wt reinforcement of graphene and the base aluminium LM6 alloy. The impact force is in KGM unit (1 KGM = 9.8066 NM).

| Sample Prepared                   | Impact force sustained (KGM) |
|-----------------------------------|------------------------------|
| LM6 alloy without reinforcement   | 0.6                          |
| 0.4% graphene                     | 0.3                          |
| 0.25% graphene                    | 0.7                          |
| 0.1% graphene                     | 0.9                          |

Figure 10: Graph comparing the test results for Impact Force Sustained(KGM) for (a) LM6 alloy without reinforcement (b) 0.1 wt% of graphene reinforcement (c) 0.25% wt% of graphene reinforcement (d) 0.4 wt% of graphene reinforcement

The graph above shows the impact strength of the composite materials manufactured. As per this graph it can be implied that the strength of the material increased when doped with 0.1 percent of graphene and while increasing the concentration, the strength is shown to decrease.

3.3. Hardness Test

Hardness is an attribute of a material, not a key physical property. Hardness is defined as the resistance to indentation, and it is calculated by measuring the permanent depth of the indentation. Hardness is the internal resistance to localized plastic deformation produced by mechanical indentation or abrasion [Science Direct reference]. Hardness of a material depends on its ductility, elastic stiffness, viscosity etc. Hardness test values is extremely useful for selecting materials, because the values indicate how well the material can be machined and how well it will wear. Hardness test was performed by using a Rockwell hardness testing machine using a 1.5875 mm diameter steel ball indenter and 100 Kg load is applied, for each sample two set of reading were taken and then the average is considered as hardness of the particular sample[8,9]. The figure 4 shows the Brinell Hardness test samples with the indentations marked.
The Table 3. Below shows the Hardness Value of the Aluminium graphene metal matrix sample with 0.1, 0.25 and 0.4% wt reinforcement of graphene and the base aluminium LM6 alloy obtained at 100N load.

| Sample Prepared          | Hardness value (HRB) |
|--------------------------|----------------------|
| LM6 alloy without reinforcement | 56                   |
| 0.4% graphene            | 55                   |
| 0.25% graphene           | 54.5                 |
| 0.1% graphene            | 56.7                 |

The results thus obtained showed that there was a minimal increase in the hardness of the metal matrix with 0.1% reinforcement of Graphene and with further increases in the weight percentage of the reinforcement there was a decreasing pattern followed up by the metal matrix. Although the graphene sheets in in the metal matrix adds hardness up to a certain level increase in the percentage also increases.
the chance of inheriting the brittle nature to the base metal thus reducing the hardness of the final matrix alloy.

After comparing the results of hardness, impact and tensile strength it was confirmed that with 0.1% weight graphene reinforcement there was betterment in the mechanical properties of the matrix but as the concentration of the graphene increased the brittle nature starts dominating over the other mechanical properties. The images shown below fortifies the brittle nature of the matrix because of the irregular crack pattern. The Aluminium matrix is not so capable to be used for impact-based purposes due to low impact absorption strength. With 0.4% Graphene reinforcement there was a large reduction in the impact strength.

3.4. Microstructural Analysis
The microstructure analysis was performed using scanning electron microscope equipped with high resolution digital camera. The surface of the sample was first polished with 200,500,1000 grains size emery paper and etched with Keller solution. The microstructure study was carried out using Zeiss metallurgical microscope. Figure 12 (a), (b) & (c) shows the microstructure of LM6 alloy reinforced with 0.1,0.25,0.4 percent graphene. The base metal is aluminium and the dendritic structure in yellow is the silicone. Observing graphene in this is very difficult. Some dark spots were found which could indicated the presence of graphene particles in a clustered form.

![Microstructure of LM6 alloy with 0.1% graphene reinforcement](image1)

![Microstructure of LM6 alloy with 0.25% graphene reinforcement](image2)

![Microstructure of LM6 alloy with 0.4% graphene reinforcement](image3)

Figure 15. (a) Microstructure of LM6 alloy with 0.1% graphene reinforcement , (b) Microstructure of LM6 alloy with 0.25% graphene reinforcement , (c) Microstructure of LM6 alloy with 0.4% graphene reinforcement

To confirm the report, FESEM and XRD analysis was conducted on each sample. XRD report, presence of carbon confirms the graphene is present and FESEM analysis is conducted to see the structure of graphene fused with the base metal in matrix. FESEM was used to obtain high resolution images of each sample. In the microstructure. It is seen that the graphene flakes are distributed randomly. Since the method of casting was stir casting and the quantity if graphene used was only 0.1,0.25,0.4 percent, detecting graphene flakes bonded with Matrix metals was difficult. After the casting was completed, the cast was machined so that we can perform the necessary test. The presence of graphene in every layer of the cast is highly unlikely. The graphene appears to be clustered together in some places which can be seen from the FESEM images. The bond between graphene and matrix metal is important as the carbon fillers helps in load transfer between reinforcements and matrix. Interfaces and strong interfacial between LM6 alloy and the reinforcement plays a crucial role in finding the tensile strength of the
composite. Reinforcement are uniformly mixed in the matrix metal due to the action of stirring in the stir casting machine. The stirring restricts the particles to float on the matrix, as the stirrer will create a vortex, which will result in the particles getting sucked in to the centre and getting mixed uniformly. The reinforcements are fully wet due to the molten matrix metal which lead to a better bonding of the particles with the metal.

Figure 16. (a) FESEM of LM6 alloy base metal(at 1000x), (b) FESEM of LM6 alloy with 0.1% graphene reinforcement(at 1000x), (c) FESEM of LM6 alloy with 0.25% graphene reinforcement(at 2600x), (d) FESEM of LM6 alloy with 0.4% graphene reinforcement(at 2000x)

Figure 13(a-d) presents the FESEM images of the Aluminium LM6 base alloy, and the metal matrix composite formed reinforcing Graphene in the LM6 alloy with the help of Stir Casting machine. The dendritic structure in the 13(a) is due to the presence of Silicon in the alloy. The graphene produced is in the cluster form instead of the layered structure. The uniform diffusion of graphene particles in the LM6 alloy matrix is achieved with the automated stir using the rotor at a uniform speed of 340 rpm. Figure 13(b) shows the clustered graphene particles on the surface of the LM6 alloy. From the SEM reports it is also inferred that with help of the stir casting and solidification using the gravity die casting reduces the number of casting defects compared to the conventional casting.

3.5. XRD Examination

X-ray Diffractograms were prepared using the X’Pert³ MRD equipment using Copper K-alpha wavelength(1.54068 Å). X-ray diffractograms are used to determine the crystalline structure of the specimen and the unit cell dimensions. The peaks in the diffractograms determine whether the material is amorphous of crystalline. If there are continuous peaks in the diffractogram then it’s a crystalline structure and each peak denotes the lattice parameter of the crystalline structure which can be calculated by the Bragg’s Equation. The theta obtained is the angle between the incident ray and the diffracted ray from the specimen so while calculating the interplanar distance and based on that the lattice parameter(h,k,l).The machine directs X-ray towards the specimen and measures the intensity of the diffracted ray, and provides a characteristics diffraction pattern. The machine collect data from range of
2Θ (ranging from 10-90°). The X-ray diffractograms for the matrix formed by reinforcing graphene in the Aluminium LM6 base metal are presented.

![X-ray diffractograms](image)

Figure 17. (a) X-ray diffractogram of LM6 alloy with 0.1% graphene reinforcement, (b) X-ray diffractogram of LM6 alloy with 0.25% graphene reinforcement, (c) X-ray diffractogram of LM6 alloy with 0.4% graphene reinforcement

From the diffractogram presented above it can be inferred that the matrix composite formed by reinforcing graphene with the Aluminium LM6 base alloy has crystalline structure. The peak intensities for the matrix were obtained at 2Θ equivalent to 38.3°, 38.15°, 38.4° for 0.1, 0.25 and, 0.4% graphene weight reinforcement with the base alloy corresponding to the lattice parameter (111) [18], apart from the peak values the other corresponding peak values for 2Θ~28.27°, 44.56°, 47°, 55.9°, 64.97°, 78.06°, 82.26°. It can also be inferred from the diffractograms that after reinforcing with the graphene particles the metal matrix didn’t lose its crystalline structure but there were some changes in the lattice orientation and the diffractograms were almost similar for the metal matrix.

4. Conclusion

The aluminium-graphene metal matrix composite was successfully created by electrochemical exfoliation graphene extraction process and stir casting method. Increase in hardness and tensile strength values indicate that the graphene can be used as an effective reinforcement for aluminium matrix. The tensile strength of the specimen with 0.1%wt of graphene reinforcement increased up to 30% as compared its parent alloy, for 0.25%wt graphene reinforcement specimen it is increased up to 25% and for the 0.4%wt reinforcement it increased up to 8% and can be stated that with increase in the reinforcement percentage of graphene in the parent alloy with the mechanical properties starts to deteriorate due to dominance of the brittle non-metallic nature of graphene as it’s one of the allotropic form of carbon. The hardness for the casted specimen with reinforcement also showed some plausible results with increase in their hardness but for the 0.4%wt it got reduced due to increase in the graphene concentration, likewise their was increase in the impact strength of the specimens, but reinforcing with the graphene particles it also imparted some brittle nature that was observed by the crack pattern on the
specimen while performing the Charpy test. The microstructure of the sample denotes that defects during the casting and solidification were reduced with the help of stir casting and there was a uniform diffusion of the graphene in the aluminium LM6 alloy, and the graphene produced was in a cluster formed instead of the planar orientation which was inferred from the FESEM images. The X-ray diffractograms showed that the metal matrix composite thus formed using the graphene reinforcement had crystalline structure with the maximum peak near around 38º having aluminium lattice parameter of (111).

References
[1] A. Saboori, C. Novara, M. Pavese, et al. An investigation on the sinterability and the compaction behavior of aluminum/graphene nanoplatelets (GNPs) prepared by powder metallurgy. Journal of Materials Engineering and Performance, Vol. 26, No. 3, 993-999, 2017.
[2] S.Gopalakrishnan, Production and wear characterization of AA 6061 matrix titanium carbide particulate reinforced composite by enhanced stir casting method. Composites: Part B 43 -2012 302- 308
[3] S. E. Shin and D. H. Bae, Deformation behavior of Aluminium alloy matrix composites reinforced with few-layer graphene, Composites Part A-Applied Sci. and Man., vol. 78, pp. 42-47, 2015
[4] Iman S. El-Mahallawi, Ahmed Yehia Shash and Amer Eid Amer, Nanoreinforced Cast Al-Si Alloys with Al2O3, TiO2 and ZrO2 Nanoparticles-Metals,2015, 5, 802-821; doi:10.3390/met5020802.
[5] El-Mahallawi, I.S.; Egenfeld, K.; Kouta, F.H.; Hussein, A.; Mahmoud, T.S.; Rashad, R.M.; Shash, A.Y.; Abou-AL-Hassan, W. Synthesis and Characterization of New Cast A356/(Al2O3) p Metal Matrix Nano- Composites. In Proceedings of the 2nd Multifunctional Nanocomposites & Nanomaterials: International Conference& Exhibition MN2008, Cairo, Egypt, 11–13 January 2008. Prabu, S.B. Influence of stirring speed and stirring time on distribution of particles in cast MMC. J. Mater. Process. Technol. 2006, 171, 268–273.
[6] El-Mahallawi, I.; Abdulkader, H.; Yousef, I.; Amer, A.; Mayer, J.; Schwedt, A. Influence of Al2O3 nanodispersions on microstructure features and mechanical properties of cast and T6 heat-treated Al Si hypoeutectic alloys. Mater. Sci. Eng. A 2012, 556, 76- 87.M. Rashad, F. Pan, A. Tang et al. Effect of graphene nanoplatelets addition on mechanical properties of pure aluminium using a semi-powder method, Progress in Natural Science-Materials International, Vol. 24, 101–108, 2014
[7] Sajjad Amirkhanlou, High-strength and highly-uniform composites produced by compocasting and cold rolling processes. Materials and Design 32 (2011) 2085-2090
[8] S.A Sajjadi, Microstructure and mechanical properties of Al-Al2O3 micro and nano composites fabricated by stir casting. Materials science and engineering A-528 (2011)8765-8771.
[9] Liang-Xu DONG, Properties, synthesis, and characterization of graphene, Qiang CHEN Laboratory of Plasma Physics and Materials, Beijing Institute of Graphic Communication, Beijing 102600, China.
[10] Sreehari Peddavarapu, Muthu Veerappan A., Raghuraman S. School of Mechanical Engineering, SASTRA Deemed University, Thanjavur 613401, India, Tribological study of Graphene reinforced AA6082 surface composite processed through Friction Stir Processing.
[14] Ajay Kumar P, Madhu H C, Abhishek Pariyar, Chandra S. Perugu, Satish V. Kailas, Uma Garg, Pradeep Rohatgi, Friction stir processing of squeeze cast A356 with surface compacted graphene nanoplatelets (GNPs) for the synthesis of metal matrix composites.

[15] Mohammad Khoshghadam-Pireyousefana, Roohollah Rahamanifarda, Lubomir Orovcikb, Peter Švecc, Volker Klemm, Application of a novel method for fabrication of graphene reinforced aluminum matrix nanocomposites: synthesis, microstructure, and mechanical properties, S0921-5093(19)31605-3

[16] Yu Zhang Ng1, a), Khi Poay Beh1, Faris Hidayat Ahmad Suahimi1, Chee Kiat Tan1, Fong Kwong Yam1, Hwee San Lim1 and Mohd. Zubir Mat Jafri1 1 School of Physics, Universiti Sains Malaysia, Penang, Malaysia, Investigation of Electrochemical-Based Exfoliation of Graphene with The Aid of Stabilizer.

[17] Prashant Tripathi, Ch. Ravi Prakash Patel, M. A. Shaz*and O. N. Srivastava* Nanoscience Centre, Department of Physics (Centre of Advanced Studies), Banaras Hindu University, Varanasi-220005, India, Synthesis of High-Quality Graphene through Electrochemical Exfoliation of Graphite in Alkaline Electrolyte.

[18] S. Venkatesan, M. Anthony Xavior, School of Mechanical Engineering, VIT University, Vellore 632 014, TN, India, Tensile behavior of aluminum alloy (AA7050) metal matrix composite reinforced with graphene fabricated by stir and squeeze cast processes.