Akshansh Mishra
Center for Artificial Intellignece and Friction Stir Welding Process, Stir Research Technologies, Uttar Pradesh, India

Mechanical and microstructure characterization of a new series magnesium metal matrix composites

Akshansh Mishra

Abstract
Magnesium matrix composites are potential materials for various applications of aerospace and defense organizations due to their low density, good mechanical and physical properties. The improvement of specific strength, stiffness, damping behaviour, wear behaviour, creep and fatigue properties are significantly influenced by the addition of reinforcing elements into the metallic matrix compared to the conventional engineering materials. This report presents an overview on the effects of different reinforcements in the magnesium and its alloy, so as to improve their mechanical and metallurgical properties. The morphology of microstructure and its effect on the physical properties of the magnesium is also discussed here. The micrograph showed that there was distribution of Boron carbide, Titanium carbide (TiC) and Carbon nanotubes (CNT) throughout the matrix. These nano particles were strengthening the magnesium nano novel composite through dispersion strengthening. Moreover, from the results, we understood that there was a considerable improvement in the tensile strength and hardness compared to the parent material.

Keywords: Metal matrix composites, super reinforced magnesium composites, carbon nanotubes powder

1. Introduction
All the mechanical industries have a very specific aim, to minimize the effort and increase the efficiency of a system. This case applies to all the diverse fields of research under mechanical engineering. For the manufacturing sector, the main motive of the engineer is to improve the mechanical and metallurgical properties of a given material. In today's fast paced developing world, we need materials which are light in weight without compromising the strength of the material [1-4]. The high strength materials can be obtained by carrying out various conventional casting techniques. Stir casting allows fabricating materials which satisfy the required conditions of the product having light weight and high specific strength. Metal Matrix Composites (MMCs) are finding increasing applications in many of today's industries. Magnesium and its alloys have gained widespread attention and popularity in scientific research as well as commercial application as energy conservation and performance demands are increasing because of their low density, approximately two-third of that of aluminium, and high specific strength compared to other structural metals [5-7]. These properties are important in automotive and aerospace applications to reduce fuel consumption. However, the application of Magnesium alloys is limited due to poor creep resistance at high temperatures and low modulus. Therefore, reinforcements are needed to improve the properties of the base metal. MMCs fabricated from magnesium will provide attractive alternatives to Aluminum MMCs. The improvement of specific strength, hardness, tensile strength, density, and other mechanical properties are significantly influenced by the addition of reinforcing elements into the metal matrix [8-11]. This research paper, presents the overview on the casting work and testing carried out on three different Magnesium composites having varying amounts of reinforcement materials, highlighting their merits and demerits. Upon extensive research in the respected and renowned journals, it was found that a lot of work has been going on fabrications of lightweight materials. So considerable number if journals were studied and came to know about the structural and mechanical properties of magnesium, especially its extremely light weight. It is further found that substantial work has been carried out with different aluminium percentages in the magnesium composites, but very limited work had been carried using squeeze casting technique with the aluminium percentages of 7%, 12% and 14%. Thus, main aim of this research is to fabricate a new series of magnesium composites with the respective new

Corresponding Author:
Akshansh Mishra
Center for Artificial Intellignece and Friction Stir Welding Process, Stir Research Technologies, Uttar Pradesh, India

proportions of aluminium. This research paper deals with the stir casting technique accompanied by squeeze casting as this method produces castings which promote recyclability of materials, are easy to dispose because they are environment friendly and clean. The fabricated materials can also be put in as a referential use for scientists and engineers to use these composites for further research as well as structural purposes.

2. Experimental procedure
Magnesium, Zinc and Aluminium ingots were taken for the composition of matrix. While Boron Carbide, Titanium Carbide and Carbon nanotubes were taken for the composition of reinforcement. The following steps were followed so as to fabricate composites with least proportions of casting defects:
- Measurement of Mg ingot by weight-950 to 990g per specimen.
- The ingot mixture of Mg, Al, Zn is preheated to a temperature of 650 degree Celsius after which the

stirring is started, while heating it to a temperature of 850 degree Celsius.
- The reinforcements (B_4C powder) are added with Carbon nanotube (CNT powder) and the mixture is pre-heated to a temperature of 300 degree Celsius in an oven.
- The powder mixture is then poured into the furnace using a funnel.
- The mixture inside the furnace is then stirred at different rpm for a period of 10min to increase the homogeneity of the mixture.
- After proper mixing by stirring, the gate of the furnace is opened and the molten composite is then transferred to the squeeze die through a runner.
- The composite is then compressed inside the die by a hydraulic press at a pressure of 40.2 tonnes.
- The composite is then cooled inside the die for 10min, and then the product is taken out of the die.
- The metal composite is then taken for the machining and finishing process.

Fig 1: Specimen after casting   **Fig 2:** Specimen after finishing

3. Composition of manufactured specimens
- **Specimen 1-SRM AL7Z1:** [Mg alloy-Al (7%), Zn (1%)] + [TiC (0.3%), CNT (1.5%)]
- **Specimen 2-SRM AL12Z1:** [Mg alloy-Al (12%), Zn (1%)] + [B4C (2%), CNT (2%)]
- **Specimen 3-SRM AL14Z1:** [Mg alloy-Al (14%), Zn (1%)] + [B4C (2%), CNT (2%)]

The specimen 1 has the base material as the AZ71 magnesium alloy whereas specimen 2 and specimen 3 are

known as SRM or Specially Reinforced Magnesium composites.

4. Mechanical and metallurgical tests
The tests that are to be conducted on the three specimens which were manufactured are as follows;

a) Tensile test: The material has been prepared according to the "ASTM A370" standards for the tensile test of the specimens. This specimen uses an apparatus called tensometer for the tensile testing of the specimens.
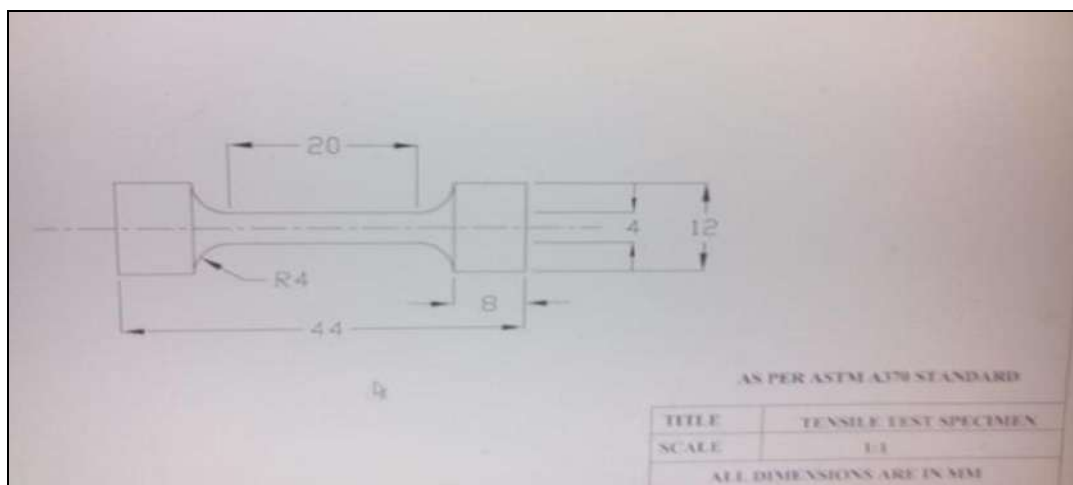

Fig 3: Schematic diagram for machining of tensile test specimens

Fig 4: Tensile Test Specimen

b) Micro vickers hardness test: The apparatus was set so as to apply 100g force on the specimen.

Fig 5: Micro Vickers hardness test equipment

Fig 6: Unpolished and non-etched surface

d) XRD and SEM Test: For XRD and SEM tests, we had to cut the specimen of initial diameter of 48.99mm to a diameter of 10mm and the thickness of the specimen should not be more than 5mm.

Fig 8: Specimen machined for XRD and SEM Test

5. Results and discussions
After the completion of all the listed mechanical and metallurgical tests, the listed results were obtained and relevant graphs were drawn in order to correlate the concepts:

c) Microstructure test: For obtaining the microstructures of the specimens at different magnifications, the surface of the specimens must be prepared in order to obtain the clear grain boundaries on the surface. For this purpose, two kinds of preparation must be carried out: Polishing of surface and Etching of surface. The surface of the specimen which is to be tested may look smooth to the coarse eyes, but when observed through a microscope, the surface contains numbers of scratches, grooves, or irregularities. This happens due to the machining work carried out on the specimen surface by the lathe machine. Hence, we are required to polish the surface with emery papers of different grades so as to increase the smoothness of the surface at a micro level magnification. Grades of Emery paper that were used for polishing were 800, 1000, 1200, 1500. The composition of the etchant used for our specimens for a clear grain boundary observation is: 92 ml of DISTILLED WATER +6ml of HNO3-65% Concentration+2ml of HF-40% Concentration.

Fig 7: Specimen after emery polishing and etching
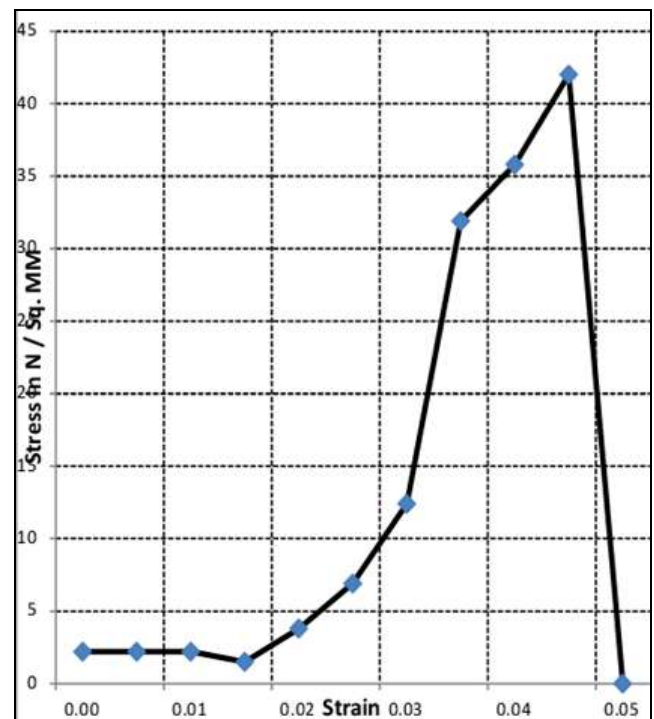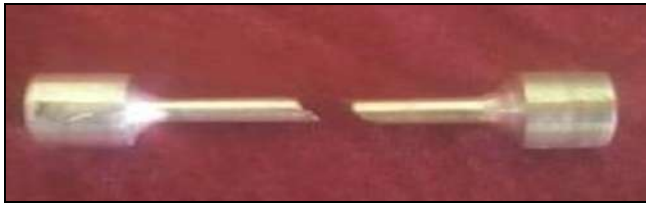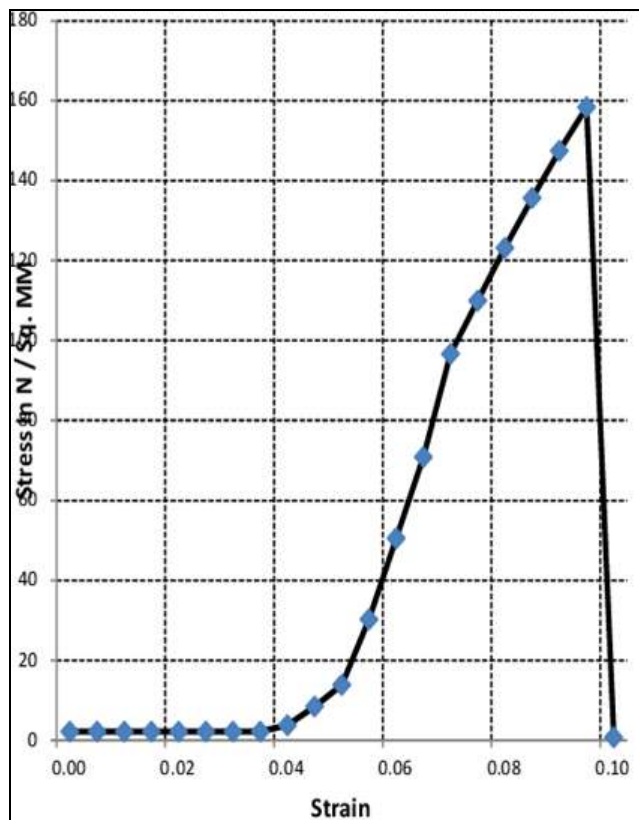
a) Tensile test

Fig 9: Stress vs Strain graph of SRM AL7Z1

Table 1: Tensile test results tabulated for SRM AL7Z1

Part	Tensile MG01
Material	MG01 GR
Test Mode	Peak/Break
High Limit	20000 N
Low Limit	10 N
Cross Sec Area	12.56 Sq mm
Sample Length	20.0 mm
Selected Load Cell	20 kN
Test Speed	5.0 mm/min
Peak Load	528 N at length: 0.9 mm
Break Load	450 N at length: 1.0 mm
Peak Disp	4.5%
Break Disp	5.0%
Ten/Cmp Stress	42.0 N/Sq mm
U.T.S.	42.0 N/Sq mm

Table 2: Tensile test results tabulated for SRM AL14Z1

Part	TENSILE MGO3
Material	MG03 GR
Test Mode	Peak / Break
High Limit	20000 N
Low Limit	10 N
Cross Sec Area	12.56 Sq mm
Sample Length	20.0 mm
Selected Load Cell	20 kN
Test Speed	5.0 mm /min
Peak Load	1754 N at length : 0.9 mm
Break Load	1754 N at length : 1.0 mm
Peak Disp	2.5%
Break Disp	2.5%
Ten/Cmp Stress	139.6 N/SQ mm
U.T.S.	139.6 N/SQ mm

From the graph, we can infer that the ultimate tensile strength for the specimen1 is very low compared to other composites which are fabricated. Aluminium percentage plays a vital role in the tensile strength of the composite.

We also observe that there is a difference between peak load and breaking load, stating that the material tested upon has undergone some amount of yielding through the tensile force acting period.

From the graph, we infer that the ultimate tensile strength of specimen 2 is higher compared to the UTS for specimen 1, almost 4 times that of the specimen 1.

We also see that the peak load and the break load are same, that is the material has not gone undergone any yielding process, stating that the material is brittle in nature.
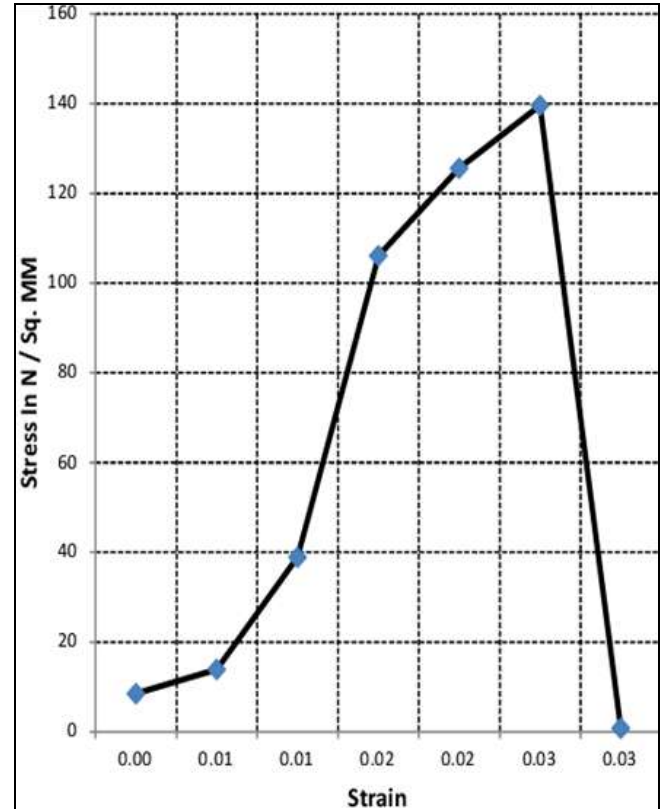

Fig 10: SRM AL7Z1 after fracture

Fig 12: SRM AL12Z1 after fracture

Fig 11: Stress vs strain graph for SRM AL12Z1

Fig 13: Stress vs strain graph for SRM AL14Z1

Table 3: Tensile test results tabulated for SRM AL14Z1

Part	TENSILE MGO3
Material	MG03 GR
Test Mode	Peak / Break
High Limit	20000 N
Low Limit	10 N
Cross Sec Area	12.56 Sq mm
Sample Length	20.0 mm
Selected Load Cell	20 kN
Test Speed	5.0 mm /min
Peak Load	1754 N at length: 0.9 mm
Break Load	1754 N at length: 1.0 mm
Peak Disp	2.5%
Break Disp	2.5%
Ten/Cmp Stress	139.6 N / SQ mm
U.T.S.	139.6 N / SQ mm

From the graph, we infer that, the UTS for specimen 3 is higher than that of specimen1 but it is lower than specimen2. This happens even if the aluminium percentage is higher in specimen 3 compared to specimen 2.

We also see that the peak load and the break load are same, that is the material has not gone undergone any yielding process, stating that the material is again brittle in nature.

Fig 14: SRM AL14Z1 after fracture

Table 4: Tensile test result comparison

Property	Cross Section area	Sample length	Peak load	Break load	Percentage elongation	Yield strength	Ultimate Tensile strength
	mm2	mm	N	N	%	Mpa	Mpa
SRM AL7Z1 [Mg alloy-Al (7%), Zn (1%)] + [TiC(0.3%), CNT (1.5%)]	12.56	20	528	450	5.0	37.8	42
SRM AL12Z1 [Mg alloy-Al (12%), Zn (1%)]+[B4C(2%), CNT (2%)]	12.56	20	1990	1990	9.5	142.56	158.4
SRM AL14Z1 [Mg alloy-Al(14%), Zn(1%)]+[B4C(2%), CNT(2%	12.56	20	1754	754	2.5	125.64	139.6

b) Micro Vickers hardness test

**Table 5:** Tabulated results for Micro Vickers

Vickers hardness	SRM AL7Z1 [Mg alloy-Al (7%), Zn (1%)] + [TiC (0.3%), CNT (1.5%)]	SRM AL12Z1 [Mg alloy-Al (12%), Zn (1%)] + [B4C (2%), CNT (2%)]	SRM AL14Z1 [Mg alloy-Al (14%), Zn (1%)] + [B4C (2%), CNT(2%)]
HV1	57.4	77.7	51.8
HV2	38.7	87.4	53.5
HV3	58.2	53.3	56.5
MEAN	51.4	72.8	53.9

The tabulated values depict the Vickers hardness of each specimen at different positions. The hardness values change with position due to presence of the reinforcement particles at that point where the hardness is taken. The hardness value will be low if the position has a micro hole at the position where the hardness is taken. We see that the hardness values for the specimen 2 have the highest values compared to the other two specimens.

c) Microstructure

The following section lists different microstructures obtained at different levels of objective lens and at different locations on the respective specimen surface:

- **SRM AL7Z1:** [Mg alloy-Al (7%), Zn (1%)] + [TiC (0.3%), CNT (1.5%)]
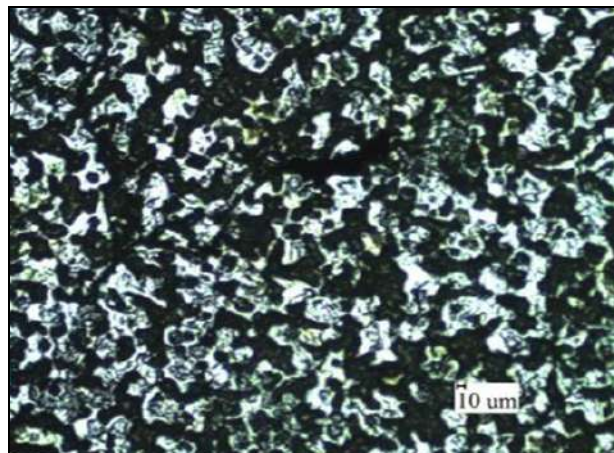
Fig 15: Magnification of 100X - SRM AL7Z1

The microstructure obtained was extremely coarse, giving possibilities for slipping between grain boundaries. The reinforcement distribution was uneven.

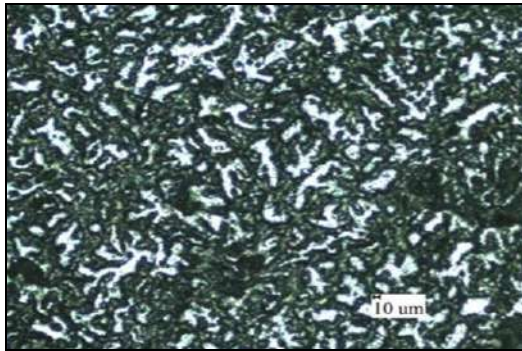- **SRM AL12Z1:** [Mg alloy-Al (12%), Zn (1%)] + [B4C (2%), CNT (2%)]

Fig 16: Magnification of 100X- SRM AL12Z1.

The microstructure was very fine compared to that of the other two specimens. Least possibility of slip and there is even distribution of reinforcement throughout the matrix.

- **SRM AL14Z1:** [Mg alloy-Al (14%), Zn (1%)] + [B4C (2%), CNT (2%)]
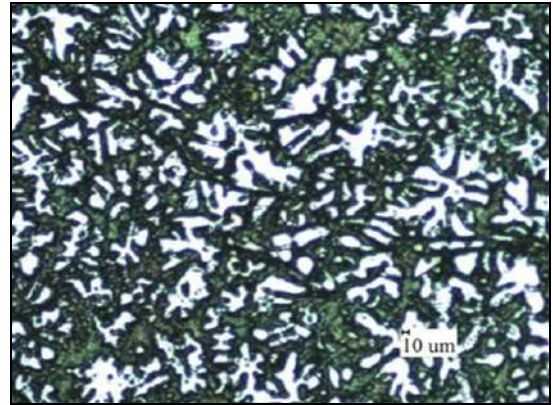
Fig 17: Magnification of 100X- SRM AL14Z1

The microstructure obtained was finer than that of the specimen 1 but coarse grain boundaries compared to that of specimen 2, giving possibilities for slipping between grain boundaries. The reinforcement distribution was slightly uneven.
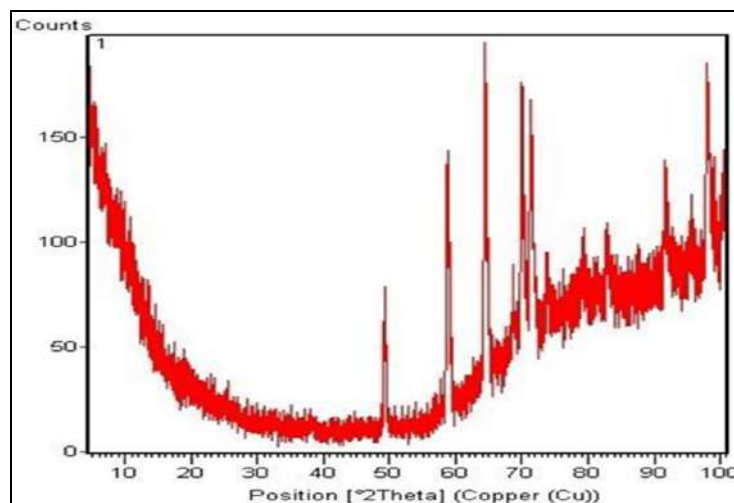
d) XRD Test

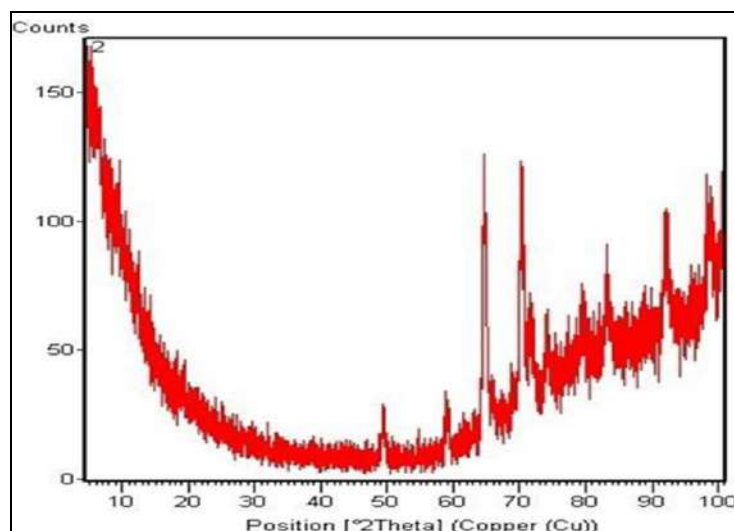**Fig 18:** XRD image for SRM AL7Z1

Fig 19: XRD Test for SRM- AL12Z1
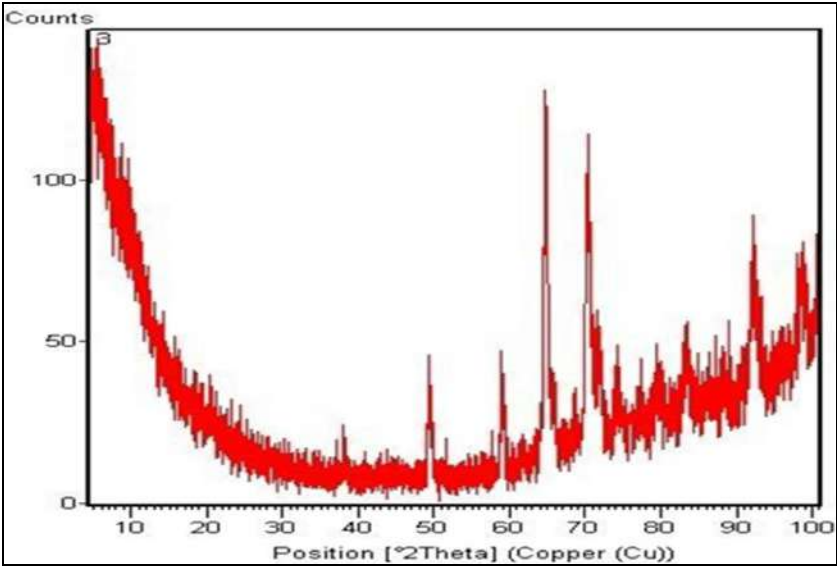
Fig 20: XRD image for SRM-AL14Z1

e) SEM Test

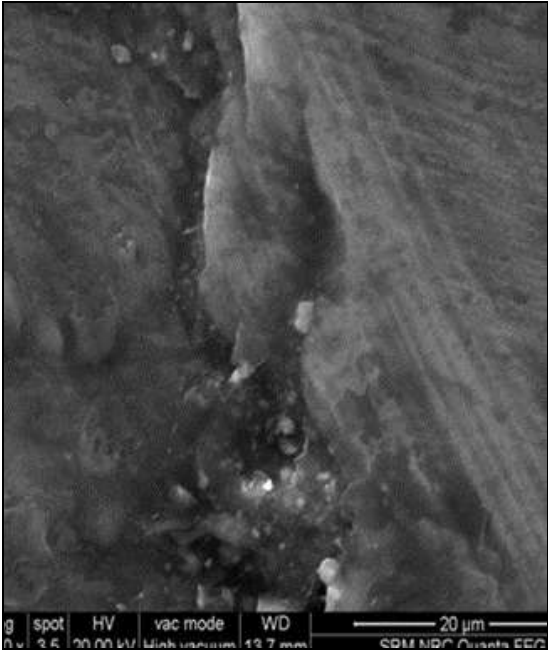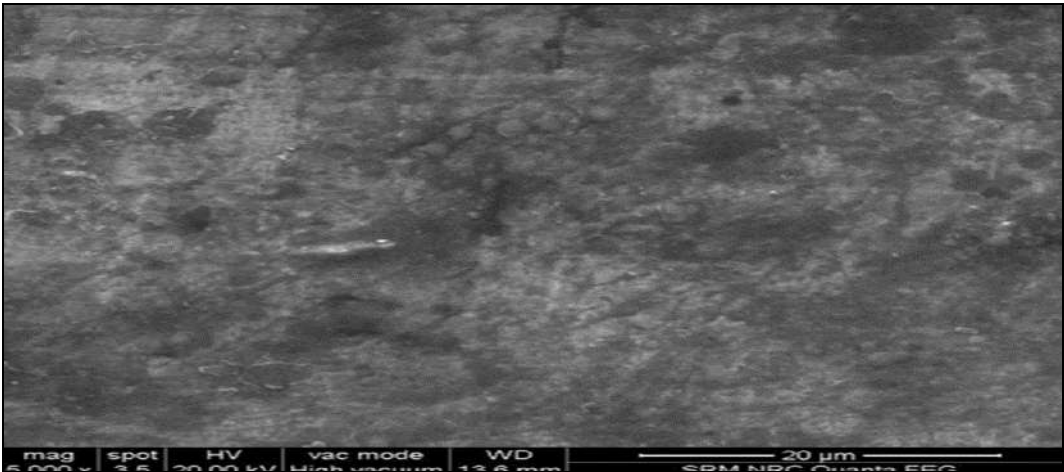**Fig 21:** SEM image at magnification of 500X- SRM AL7Z1

Fig 22: SEM image at magnification of 1300x- SRM AL12Z1

6. Conclusions

- The new novel magnesium composite were produced successfully by different reinforcements
- From the Micro Vickers hardness tests, we found out that SRM AL12Z1 has comparatively higher hardness than the other two specimens
- SRM AL12Z1 yielded at a hardness of 72.8 VH, while SRM AL7Z1and SRM AL14Z1 showed the hardness has 51.4 VH and 53.9 VH respectively.
- After conducting the tensile tests, we also inferred that the UTS of SRM AL12Z1 was higher than SRM AL7Z1 and SRM AL14Z1.
- The UTS for SRM AL12Z1 was at a value of 158.4Mpa while for SRM AL7Z1 and SRM AL14Z1, it was 42Mpa and 139.6Mpa respectively.
- Aluminium and CNT reinforcement provides high tensile strength, thus opening up the possibility that the variation in amount of Al in the three different specimens might have affected the given tensile strength values.
- Upon observing the microstructure images, we concluded that the reinforcements were evenly distributed among the entire matrix, thus inferring that stir casting is a viable method of casting.
- This even distribution of the reinforcements promoted high values of hardness and tensile strength in the fabricated composites, compared to the parent material.
- The above stated results were verified by the microstructure images when the images for SRM AL12Z1 showed extremely fine grain structure, thus promoting minimal slipping between the grains. The microstructure images for SRM AL7Z1 showed highly coarse grain structure, thus giving the reason to believe that there might have occurred slipping of the grains when the specimens were acted upon by loading factors.

References

1. Zhang MH, Gjvorv OE. Mechanical properties of high-strength lightweight concrete. Materials Journal. 1991; 88(3):240-247.
2. Park SB, Yoon ES, Lee BI. Effects of processing and materials variations on mechanical properties of lightweight cement composites. Cement and concrete research. 1999; 29(2):193-200.
3. Mor A. Steel-concrete bond in high-strength lightweight concrete. Materials Journal. 1993; 89(1):76-82.
4. Soroushia P, Nagi M, Okwuegbu A. Freeze-thaw durability of lightweight carbon fiber reinforced cement composites. Materials Journal. 1992; 89(5):491-494.
5. Eliezer D, Aghion E, Sam Froes FH. "Magnesium science, technology and applications". Advanced Performance Materials. 1998; 5(3):201-212.
6. Kulekci MK. Magnesium and its alloys applications in automotive industry. The International Journal of Advanced Manufacturing Technology. 2008; 39(9-10):851-865.
7. Polmear IJ. Magnesium alloys and applications. Materials science and technology. 1994; 10(1):1-16.
8. Alahelisten A, Bergman F, Olsson M, Hogmark S. On the wear of aluminium and magnesium metal matrix composites. Wear. 1993; 165(2):221-226.
9. Luo A. Processing, microstructure, and mechanical behavior of cast magnesium metal matrix composites. Metallurgical and Materials Transactions A. 1995; 26(9):2445-2455.
10. Bakkar A, Neubert V. Corrosion characterisation of alumina–magnesium metal matrix composites. Corrosion Science. 2007; 49(3):1110-1130.
11. Dey A, Pandey KM. MAGNESIUM METAL MATRIX COMPOSITES-A REVIEW. Reviews on Advanced Materials Science, 2015, 42(1).