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Microstructure analysis and Hardness of Al C355.0 with step varying weight of Hematite particulate reinforcement

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Abstract. A detail study on the microstructure of engineered Al C355.0 metal matrix with step varying weight of hematite particulate reinforcement from 0–12% in the step of 3% by using stir casting method in the copper chills with and without water circulation is carried out in the present work. It was earlier realized that copper chills increase the hardness of metal matrix compared to its base alloy. The novelty lies in the circulation of water during solidification process so that a stronger matrix reinforcement bonding, low cluster regions, grain reinfinement with minimum porosity could be achieved. The maximum hematite particulate size was 150 µm. From the Scanning Electron microscope, it is clear that there was good distribution of reinforcement in the matrix but not exactly clear whether it is uniform or non-uniformly distributed. SEM and XRD analysis results show the presence of hematite in the matrix. With increase in reinforcement the hardness increased up to 9% of the reinforcement and then decreased. It is concluded that water circulation on casted composites have good effect in improving the hardness of the Al C355.0 at 9% of hematite resulting to BHN 128 and without water circulation it was found to be BHN 124. It is realized that water circulation improves the hardness of the composite for all the cases with hematite as particulate reinforcement for Al C355.0.

Key words: copper chills, hematite, microstructure, water circulation.

INTRODUCTION

In various field of engineering like defence, aerospace sector, automobiles and mobiles metal matrix composites are very extensively used for the sole reason being high strength to low weight. A good composite material characteristic could be achieved by suitable selection of reinforcement and matrix, this unique feature of composites helps achieve desired material properties and find wide applications. Stir casting technique in the present work was used after the comparison of different casting process it was inferred that the stir casting was the simplest and most cost-effective techniques that also provides good scattering of particles in the metal matrix for the sake of manufacturing metal matrix composites (Panwara & Chauhan, 2018). The importance of stir casting was that the stir casting resulted in fair distribution of reinforcement particles. Metal matrix composites were manufactured by varying the reinforcement SiC in wt%. It was inferred that stir casting techniques was successful in preparation of Al 7075-SiC and a good distribution of SiC was obtained in the matrix and Vickers micro hardness showed that the composites with SiC possess large values compared with their base alloys (Gosavi & Jaybhaya, 2021). Keeping in view the advantages the present work used the technique of stir casting. In the present work a step varying weight of hematite was from 0–12% is studied in an increment of 3% to know the effect of particulate reinforcement on the hardness of the material. The results obtained were similar to the microstructure of the Aluminum matrix composites using the graphite as reinforcement for Al 6082 and was concluded that at 12% of Gr microstructure the study showed that a uneven distribution of graphite was taken place for all different weight % of the graphite reinforcement. And also, the hardness of the composite decreased with the increase in the weight percentage of the Gr (graphite) (Sharma et al., 2018). Influence of reinforcements can clearly be seen on the microstructural and mechanical properties was taken up. Disposal waste of coconut shell fly ash with varying wt% of SiC was used as reinforcement for Al 6061 melt matrix. Microstructural analysis showed that density increased for a more Wt.% of the reinforcement (Al6061+4% CSFA +10%SiC) along with the hardness values (Hillary et al., 2022). A 5wt% Al_2O_3 and SiC particulate reinforcement with a melt matrix Al-4% Cu-2.5% Mg was engineered through stir casting process. Micro structure revealed that there exist well dispersed particles along with small porosity at different locations. Al -4% Cu -2.5% Mg / 5% of SiC showed brittle nature were as Al -4% Cu -2.5% Mg / 5% of Al2O3 composite showed ductile nature (Yigezu et al., 2013). A metal matrix hybrid composite was fabricated by the technique stir casting technique. Density of composite decrease with the increase in the presence of reinforcement and a similar trend was identified for the hardness of the composite. There was decrease in hardness with the increase in wt% of the reinforcement (Ahamad et al., 2020). Al 6063 based metal matrix composite that is reinforced with Al_2O_3, SiC and TiO_2 have better hardness than the base alloy. Compared to all the other reinforcements the SiC showed better mechanical properties (Shuvho et al., 2020). Study on the microstructure of the AZ91D alloy using squeeze casting technique and it was noted that the alloy was non- uniform and consists of chilled layer, segregation zone, pressurized crystallization area and hot pot area as different zones for the composite (Yang et al., 2011). Different Particulate SiC was mixed with Ag-Cu-Ti powders to obtain a SiC reinforced composite through the technique of tape casting process. It was inferred that with the SiC particulate increase the joining strength at room temperature and later was found to be decreased due to mismatch and the thickness of the reaction layer (Liu et al., 2015). Influence of the mixed rare earth metals as reinforcement could refine the microstructure of the resulting alloy also it was concluded that the mechanical properties improved upon considering the rare earth metals (Song & Yan, 2020). Hybrid matrix composite (Al-SiC-kaoline) which was fabricated through powdered metallurgy technique was investigated. With the increase in the kaoline reinforcement, density decreased and hardness of the composite increased. The fabricated samples showed absence of pores (Venkatesh & Deoghare, 2022).

Influence of La (Lanthanum) and Ce (cerium) on Al-Si-Cu-Mg-Fe alloy was in detail studied and it was inferred that addition of Ce and La had shown no significant influence on the hardness of the composite material even after increasing the particulate fraction. At microstructure level the addition of (Ce and La) results in the formation of plate like phases (Du et al., 2021). Friction stir processing (FSP) route technique is followed for Aluminum hybrid metal matrix with reinforcement of ZrO_2 and nickel particles and also hybrid reinforcement (varying combinations of ZrO_2 and Ni). At microstructure level it was inferred that the distribution of reinforcements was homogenous and no deleterious intermetallic compounds are formed (Patel et al., 2022). Laser surface alloying of aluminum with SiC and TiO_2 has resulted in Al4SiC4 and Al3 Ti compounds that in turn enhanced micro hardness. Greater hardness is achieved by TiO_2. The grain structure has been refined by Laser melting and fast solidification that led to the improvement of the hardness in the composite (Woldetinsay et al., 2017). Aluminum alloys-based Al-Ca-Zn-Mg system was reinforced with thermo-calc for optimization of the fabricated composite. It was inferred that the hardness level was maximum for the calcium -containing alloys (Belov et al., 2017). An attempt has been made to achieve an uniform distribution of the reinforcement (TiC) in the matrix alloy (Al7075) by varying the process parameters such as stirring speed, stirring time. An increase in the process parameters resulted in the better distribution of the reinforcement particles which in turn enhanced micro-structure and mechanical properties. Hardness value has significantly increased by increasing TiC reinforcement (Scaria & Pugazhenthi, 2021). A 25 wt% of born carbide (B_4C) particulate reinforcement in aluminum 1100 matrix was fabricated at 873k and from the dark-field images it is realized that there exists porosity. Further, it was also inferred that ductility of the metal matrix composites may be improved by the increase of the interfacial bonding and decreasing overall porosity contents of the composite (Mohanty et al., 2008). Mechanical properties for Al 5059 matrix MMCs reinforced with Al_2O_3, SiC and B_4C of varying particle size of 130, 250 and 30nm respectively. Tensile tests showed an increase in yield strength compared to the base matrix after containing nano scale Al_2O_3, SiC and B_4C at composite respectively. The nano -scale particles increase the hardness of the produced composites (Sahraeinejad et al., 2015). Different wt% of ranging from 0–15% wt in a step of 5% each for the SiC reinforcement in the Aluminum metal matrix is taken up. Micro structural analysis showed that fair distribution of reinforcing particles along with some clustering and porosity in the material. The hardness of the material also increased (Ajagol et al., 2018). Thermal stability of different alloys was compared and microstructural analysis and hardness tests were performed. Inference was A201 had best thermal stability (Gao et al., 2018). Also, advanced technology materials such as NiWC, CoWC are proven to have very good mechanical and physical properties for elevated temperature applications (Yonetken & Erol, 2016). After extensively going through the available literature on different reinforced composites and manufacturing techniques, the authors feel that is is good to go with simplest stir casting technique with the reinforced particulate hematite as it was not tested for an Al C355.0 base metal matrix composites and also to know how the incorporation of hematite particulate reinforcement effects the hardness of the composite, particulate redistribution in the matrix (uniform ,non-uniform) through water circulation in copper chills.

MATERIALS AND METHODS

Aluminum C355.0 reinforced with Hematite particles whose average size is of 150 µm composite has been fabricated using a stir casting technique. The hematite (Fe_2O_3) powder was preheated at 350 °C before introducing into the molten metal vortex which was heated to 850 °C (AlC355.0). The stirring was done at 200 motor rpm for a stirring time of 10 minutes. A total of 10 samples by varying hematite from 0–12% in a step of 3% is taken up and was cooled in the copper chills with and without water circulation (water circulation trough pump). The water circulation is achieved through a motor that pumps 5.5LPM and operates at 9 bar pressure. The molten AlC355.0 metal matrix was obtained from FENFE Metallurgical, Ramnagar, Bangalore. The composition of Al C355.0 is shown in the Table 1. In addition, 4% weight of magnesium chips to the Aluminum C355.0 alloy has been added to help in flowability of molten metal and wettability of SiC particles in the aluminum matrix and reduce the surface tension of molten aluminum.

Table 1. Al C355.0 alloy Composition

Sl. No	Constituent	Percentage (%)
1	Si	5.5
2	Mg	0.6
3	Fe	0.2
4	Cu	1.5
5	Mn	0.1
6	Ti	0.2
7	Zinc	0.1
8	Al	91.65

Hematite particulate

Hematite is a heavy and hard oxide mineral and is a most important iron ore because of its iron content. Table 2 shows the composition of the hematite. Particulate hematite along with EDS analysis is shown in Fig. 1.

With the increase in the hematite reinforcement there was increase in the hardness first increased then it decreased and least is observed for 12% hematite reinforcement for C355.0. as shown in Fig. 2. The reinforced particles float in large amounts and leads to large impurities on the surface and this in turn was expected to develop cracks there by increased reinforcement beyond certain value resulted in reduced hardness. The trend for the hardness is similar for with and without water circulation.

Table 2. Composition of Hematite

Sl. No	Constituent	Percentage (%)
1	Fe_2O_3	81.13
2	MnO	0.14
3	MgO	1.55
4	TiO_2	0.03
5	Al_2O_3	0.57
6	CaO	4.8
7	SiO_2	4.2

The best hardness value was for 9% hematite reinforcement for C355.0 with water circulation and the same is also true for without the water circulation. For 6% hematite reinforced C355.0 composite, there exists particle free zones these particle free zones are absent for 9% hematite reinforced composite.

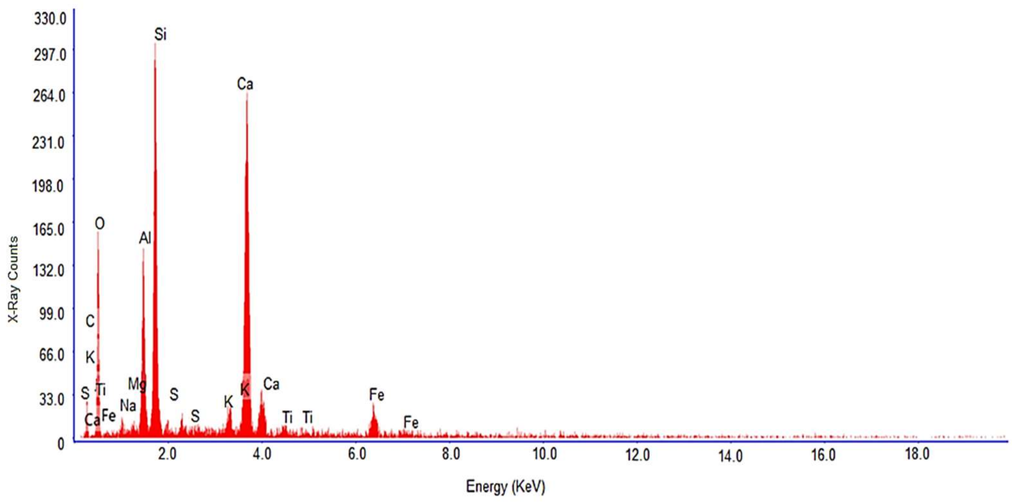


Figure 1. EDS analysis of hematite particulate reinforcement.

Good grain distribution could be visible when the composite is circulated with water as shown in the above SEM images. All The hardness samples were prepared at standard ASTM E10. Hardness testing Machine [mechatronic control system, capacity 3,000 kgf, 10MM ball indenter.

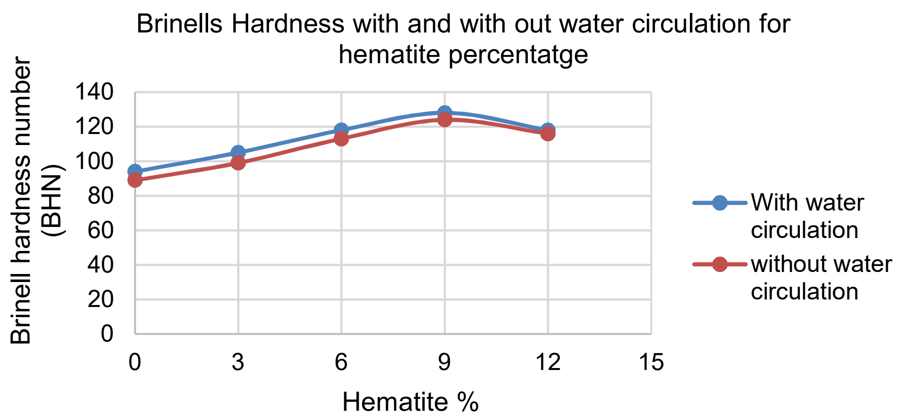


Figure 2. Brinell Hardness test results for 500 kgf load with 10 mm ball indenter (a) with water circulation (b) Without water circulation.

The properties of reinforcement hematite have a density of 5.3 g cm^{-3} and a melting point from 1,475 °C – 1,565 °C. SEM images for different weight varying percentage of hematite in the composite were carried out. XRD outcomes of the fabricated composite was to cross verify all the elements that are present in the engineered composite.

The dimensions and the setup used is shown in the Fig. 3.

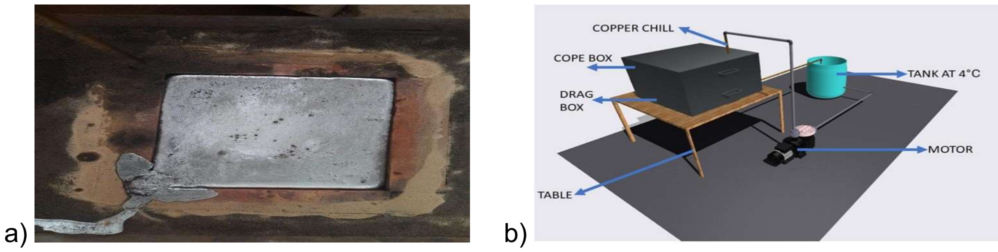


Figure 3. (a) Solidified composite with diemsion 150 mm x 100 mm; (b) Setup with copper chills and motor for water circulation.

RESULTS AND DISCUSSION

Pure Al C355.0 SEM images be seen in the Fig. 4. for the composite material with and without water circulation. Particle free zone could be seen for matrial with water circulation where as clusters are formed without the water circulation.

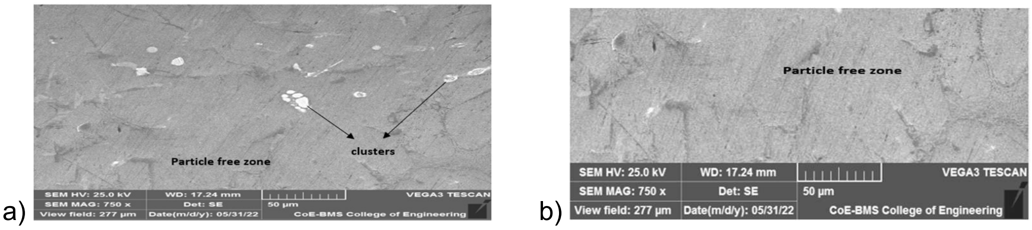


Figure 4. (a) Microstructure of Al C355.0 with 0% hematite without water circulation (b) with water circulation.

The SEM images of Al C355.0 reinforced with 3% hematite with and without water circulation is shown in the Fig. 5. It can be inferred from the SEM images that a good distribution of the reinforcement particles could be achieved by using the water circulation method. There were just few cluster regions what so ever formed or seen. But for same 3% hematite reinforcement without water circulation, many cluster regions could be seen and also the distribution of the reinforcement was not so good as compared to the water circulated 3% hematite fabricated composite.

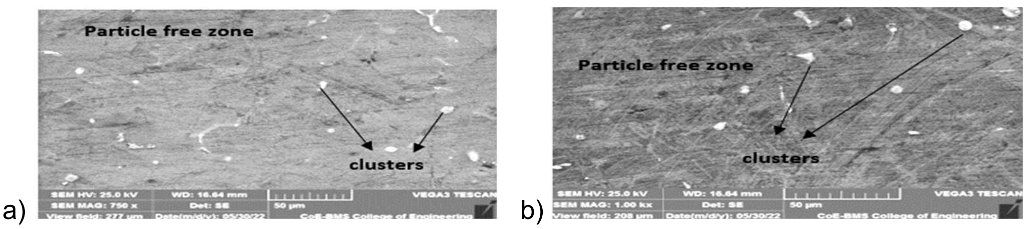


Figure 5. Microstructure of Al C355 3% hematite reinforced composite (a) with water circulation (b) without water circulation.

With 6% hematite reinforcement with and without water circulation, in the case of water circulated composite a good distribution of hematite particles could be seen and there exists just one or two cluster regions but without water circulated composite there exists multiple clusters. The results can be seen in Fig. 6.

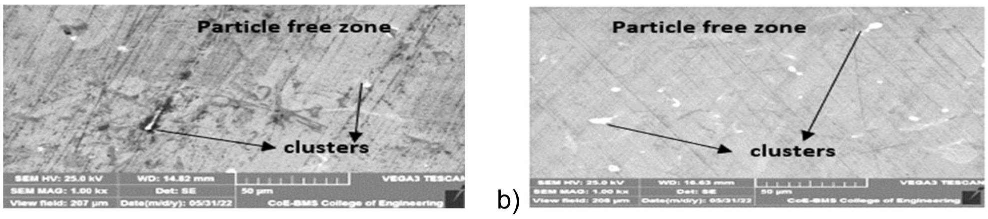


Figure 6. Microstructure of Al C355.0 with 6% hematite reinforced composite (a) with water circulation (b) without water circulation.

In a similar way, with 9% of hematite with water circulation SEM image results show no cluster formation and distribution of the reinforced particles was good. but for 9% hematite without the water circulation, very little cluster formation was seen and distribution of reinforcement was not very good as can be seen from Fig. 7. The reason could be due floating of hematite particles.

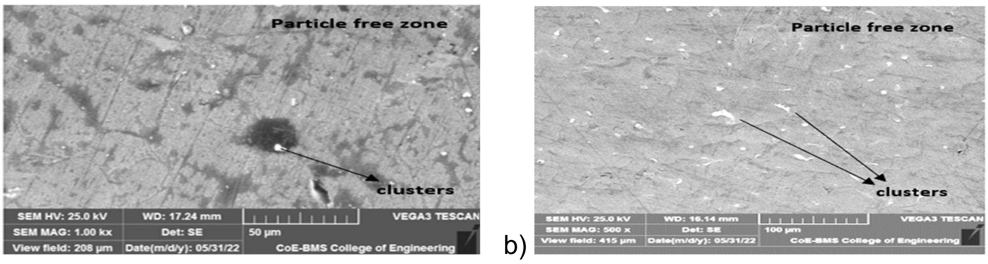


Figure 7. Microstructure of Al C355.0 with 9% hematite reinforced composite (a) with water circulation (b) without water circulation.

For a 12% hematite reinforcement C355.0 with water circulation, SEM image results show a not so good reinforcement distribution along with more cluster region is seen. for the composite without water circulation that resulted in poor distribution of reinforcement and many cluster zones as can be seen in the Fig. 8.

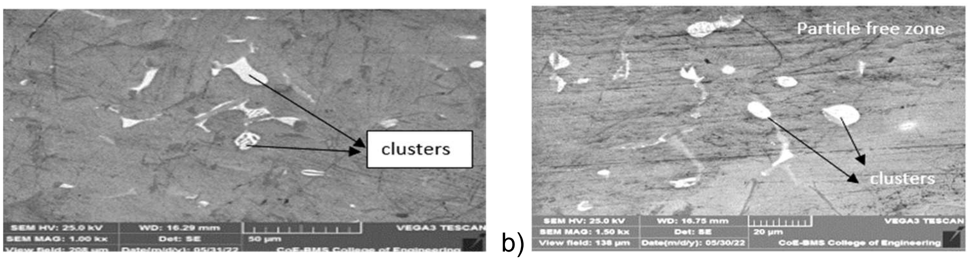
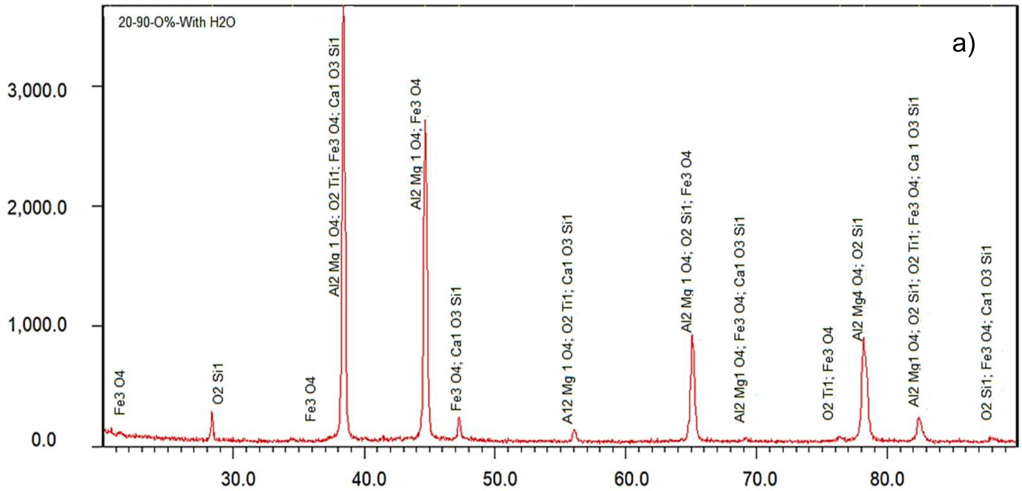


Figure 8. Microstructure of Al C355.0 with 12% hematite reinforced composite (a) with water circulation (b) without water circulation.

In the Fig. 9 XRD results of As cast C355.0 with and without water circulation is shown. XRD analysis show main elements or constituents present are Al (Aluminum), silicon, copper, Magnesium, Iron, Titanium, Manganese and zinc. The results also show the absence of Hematite particles.



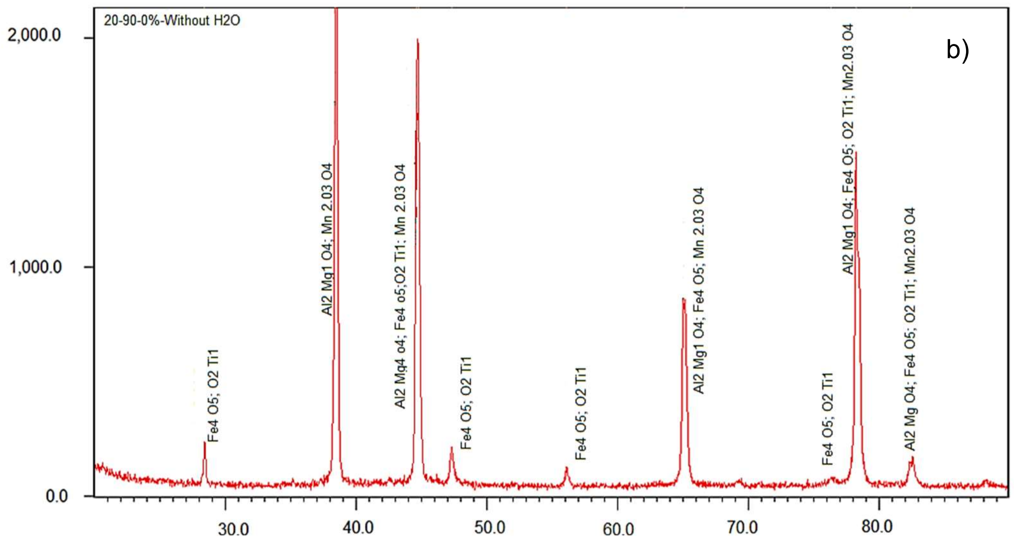


Figure 9. XRD results for 0% hematite reinforced composite (a) with water circulation (b) without water circulation.

From the Fig. 10 the XRD results show the presence of Si (silicon), Fe (ferrous) and also proves that the composite contains hematite particulates.

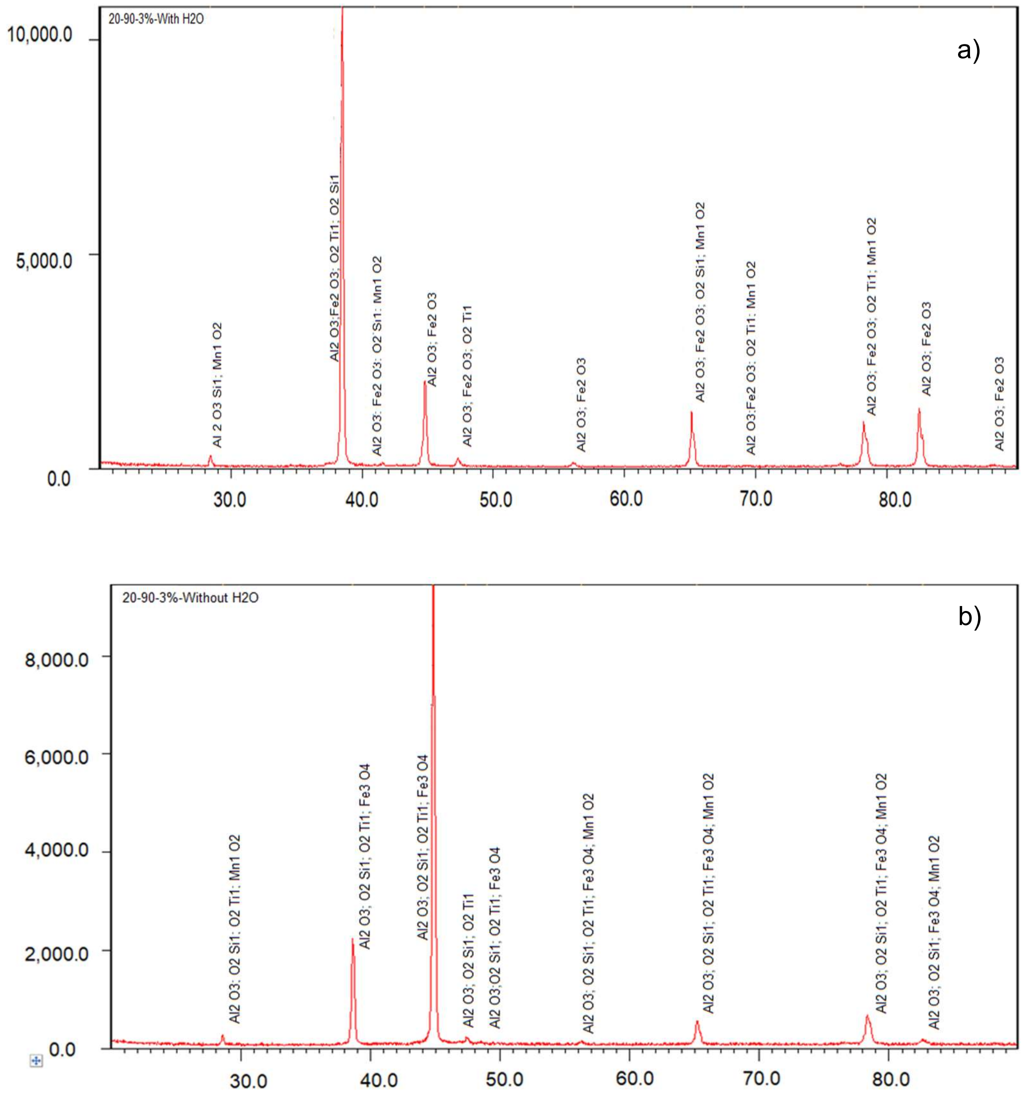


Figure 10. XRD results for 3% hematite reinforced composite (a) with water circulation (b) without water circulation.

The XRD results for 6% hematite composite material with and without the water circulation is shown in Fig. 11. The different peaks values for Fe_2O_3, SiO_2 and Aluminum (Al) show the presence of reinforcement in the composite.

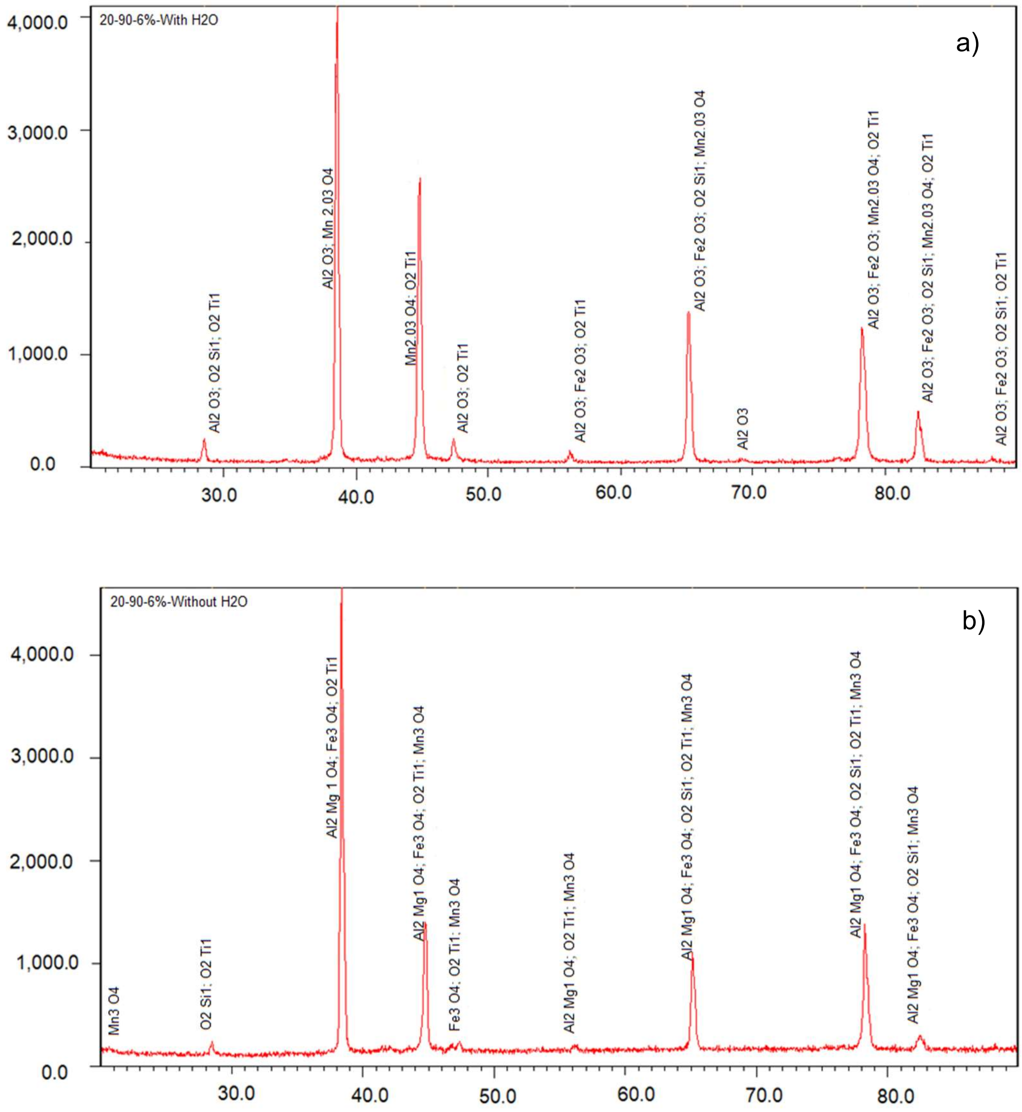


Figure 11. XRD results for 6% hematite reinforced composite (a) with water circulation (b) without water circulation.

The XRD result analysis for 9% hematite reinforcement is shown in Fig. 12, a more peak values compared to the 0–6% of hematite reinforcement could be seen. for a higher peak value, it is concluded that there is more reinforcement. Similarly in Fig. 13, the presence of freinforcement can be clearly noted.

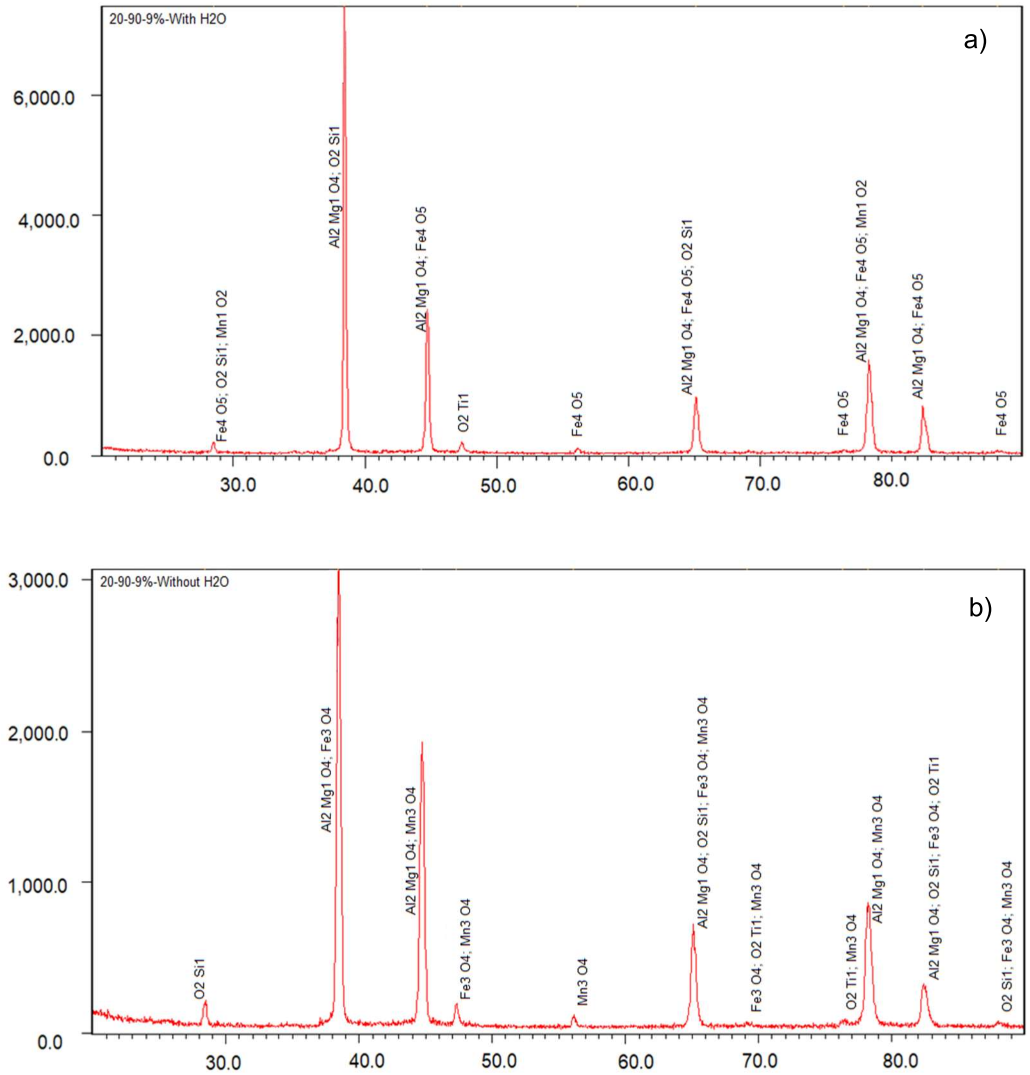
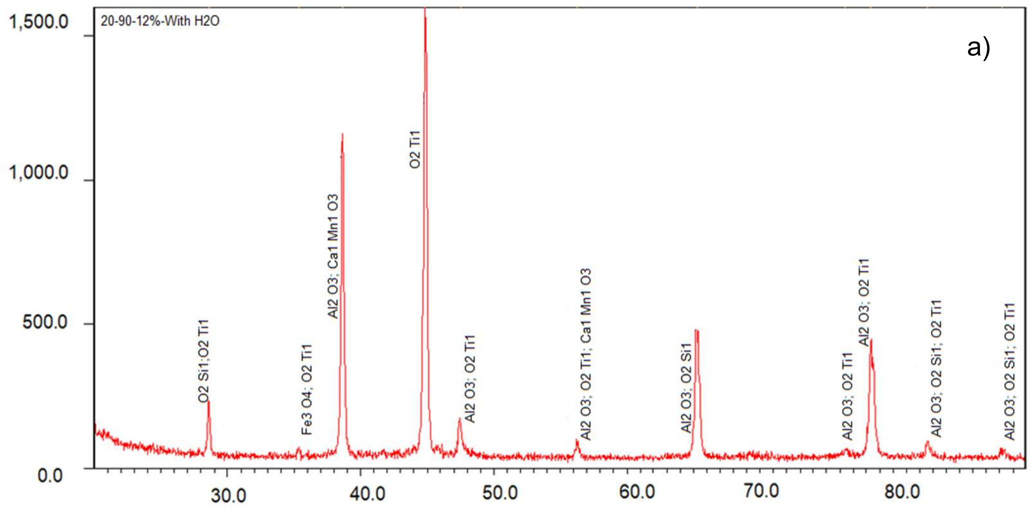


Figure 12. XRD results for 9% hematite reinforced composite (a) with water circulation (b) without water circulation.



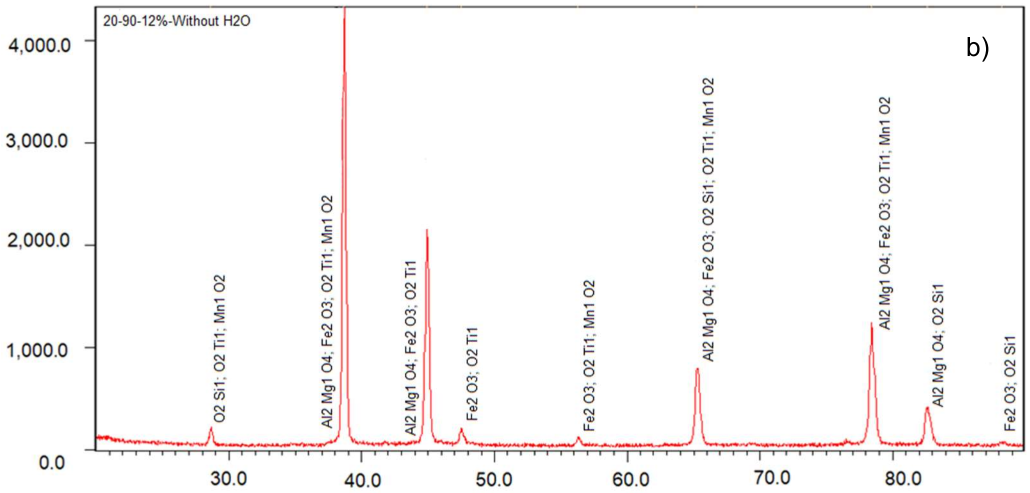


Figure 13. XRD results for 12% hematite reinforced composite (a) with water circulation (b) without water circulation.

The stir casting technique importance as mentioned by (Panwara & Chauhan, 2018) was taken into consideration for the present work. The results obtained are in similar trend with (Sharma et al., 2018). The 12 wt% of Hematite the hardness decreased. With the increase in the weight % of hematite composite. As mentioned by (Ahamad et al., 2020), a similar trend in the density of the composite material is decresed with the increase in wt% of the reinforcement material.

CONCLUSIONS

The microstructutre of the AI C355.0 with and without water circulation during solidification is studied. The current work only considers the BHN brinell hardness number and its relation to the changes in the microstructure through SEM and XRD analysis. It is anticipated that a 9% weight Hematite sample would show better results for other mechnaical properties like toughness, yield strength and corrosion.

The following inferences was drawn from the present study:

- The reinforcement distribution and hardness were found to be good for 9% hematite reinforced Al C355.0 with water circulation.
- Water circulation help good distribution of the hematite reinforced particulates.
- Presence of hematite reinforcements were observed in XRD results for all weight varying reinforcement cases.
- It is realized that copper chills increase the hardness compared to the base metal alloy along with directional solidification of the melt there by a better variation in the microstructure and mechanical properties to be achieved.
- Also, there was no interphase bonding between reinforcement and matrix.
- The presence of clusters would decide the hardness of the material as mentioned. The more clusters presence would reduce the hardness of the material as these clusters formations would result in poor matrix and reinforcement bonding.

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