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Optimization of Stirring Speed and Time in Achieving Sound A356-Sic MMCs and its Effects on Microstructure and Mechanical Properties

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Abstract

Stirring is an essential and important factor in stir casting process of Liquid Metallurgy (LM) to achieve homogeneous dispersion of the reinforcements in the matrix. In the present study two important parameters of stirring, such as stirring time and speed were optimized for the preparation of sound A356-SiC Metal Matrix Composites (MMCs). The effect of stirring speed and time on microstructure of A356-10%SiC MMCs were analyzed using Scanning Electron Microscopy (SEM), Energy-dispersive X-Ray Spectroscopy (EDX) and X-Ray Diffractometry (XRD). The experiments were carried out for different stirring speed and time varying from 250, 350, and 450 rpm and 5, 7, and 9 minutes respectively. Initially stirring time was optimized and was found to be 7 minutes at a constant stirring speed of 350 rpm. And this optimized stirring time of 7 minutes is considered for further experiments while optimizing stirring speeds. Increase in the stirring speed and time from 5 minutes and 250 rpm resulted in homogeneous distribution of SiC particles in A356 matrix without having any agglomeration or segregation. Further, at the stirring speed of 350 rpm and stirring time of 7 Minutes a sound A356-SiC MMCs were obtained. Increases in stirring speed and time, on the other hand, resulted in the loss of microstructural characteristics. Finally, a stirring speed of 350 rpm and a stirring period of 7 minutes were discovered to be the ideal speed and time for achieving maximal tensile strength and hardness.

Keywords: *Casting, Liquid Metallurgy, Microstructure, Metal Matrix Composites, Stirring Time, Stirring Speed*

1.0 Introduction

To address the needs of industry, it is critical to introduce new materials. Composite materials stand first in this category for various applications[1]. Due to their mechanical and thermal qualities, composite materials are the most competitive materials utilised in structural and non-structural parts of automotive, aerospace, and transportation industries. Combining the qualities of metal and ceramics is the fundamental goal while designing MMCs. When reinforced into a ductile Aluminum matrix, ceramic reinforced materials have high strength and modulus, resulting in a material with better mechanical properties intermediate to matrix and reinforcement materials. Thus, the low stiffness of the metal can be improved by adding a high stiff ceramic

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reinforcement material, and hence making a composite material a right candidate for specific industrial applications.

Because of its high mechanical qualities, such as resistance to wear, low thermal expansion coefficient and high thermal conductivity, SiC has been used as reinforcement in Al MMCs for decades. Production of SiC reinforced Al MMCs is more economical compared to other counterparts[1-3]. Processes to develop these MMCs vary considerably based on the type of reinforcement material. Various techniques are employed for production of MMCs[2,3]. Stir casting method is most economical and effective for production of large castings among the available processes[3-6]. The stir casting process, on the other hand, is commonly employed in the manufacture of MMCs. Where as certain technical challenges need to be addressed and they are[3,7-9],

1. Achieving low porosity and uniform dispersion of particles to have uniform mechanical properties,
2. Wettability to have better load transfer.
3. Avoiding chemical interactions between reinforcement-matrix[10].

MMC processing has been the subject of extensive research by stir casting methods under liquid and semisolid conditions[3,7,8,11-17]. However, little research is reported on stirring speed and time for uniform dispersion of reinforcement material in achieving uniform mechanical properties. This is an important factor in processing of MMCs. Hence, the present work is focused on optimizing the stirring speed and time for different SiC particle size.

2.0 Experimental Details

Stir casting was used to make A356-SiC composites using standard methodology. To form the vortex in the melt, the temperature was kept around ~700 ± 10 °C and the melt was agitated with a mechanical stirrer. The preheated 15 percent SiC particles were poured into the melt vortex through a funnel at this point. Preheated SiC particles results in formation of a lean oxide layer of SiO_2 on the surface that may restricts SiC reacting with Al alloy and prevents the formation of Al_4C_3 and Si[21-23].

The samples were prepared with different stirring time of 5, 7, 9 minutes, for a constant speed of 350 rpm. Once we achieve an optimum stirring time, further stirring speed experiments were conducted at 250, 350, and 450 rpm at a constant optimum stirring time. To avoid contamination of the A356 melt, all tools that come into touch with it were coated with zirconia. The stirrer was immersed to a depth of about 2/3 the depth of the molten metal. To make the specimen, a preheated cast iron mould (250^{0}C) was employed.

3.0 Results and Discussion

For composite to be used as component for industrial applications, it is very much necessary to have a homogeneous dispersion of reinforcement particles to maximize the mechanical properties. It is critical to have control over the stir casting process in order to produce homogenous dispersion of reinforcement particles and maximise mechanical qualities. The parameters to be given importance are related to stirring i.e. stirring speed and time.

In this experimental study, stirring time of 5, 7, 9 minutes are considered at a constant stirring speed of 350 rpm. Once we achieve optimum stirring time of 7 minutes, stirring speed experiments were conducted at 250, 350, 450 rpm at a constant and optimum stirring time of 7 minutes. As cast A356-SiC MMCs prepared at various stirring speeds and stirring times were characterized by optical microscopy, SEM/EDX analysis and XRD. For the various samples used, mechanical parameters like as hardness and tensile qualities were compared and analysed for getting the optimized values for stirring speed and time for producing sound castings of A356-SiC MMCs.

3.1 Microstructure Analysis of A356 Alloy

Figures 1(a) and (b) shows the optical photomicrograph of as cast A356 alloy prepared by using LM route. α-Al primary phase is seen as white phases in the optical micrograph and are dendritic in morphology. Also, the colour of the eutectic mixture of aluminium and silicon (Al-Si) is grey. Between the dendritic arms, the hypoeutectic A356 alloy develops α-Al primary phase and an Al-Si eutectic phase. This occurs throughout the solidification process, as well as the precipitation of the Mg_2Si phase.

Figures 1(a) and 1(b) show finer eutectic silicon particles scattered along the grain boundary, as well as some flake-like eutectic silicon particles. Also observed

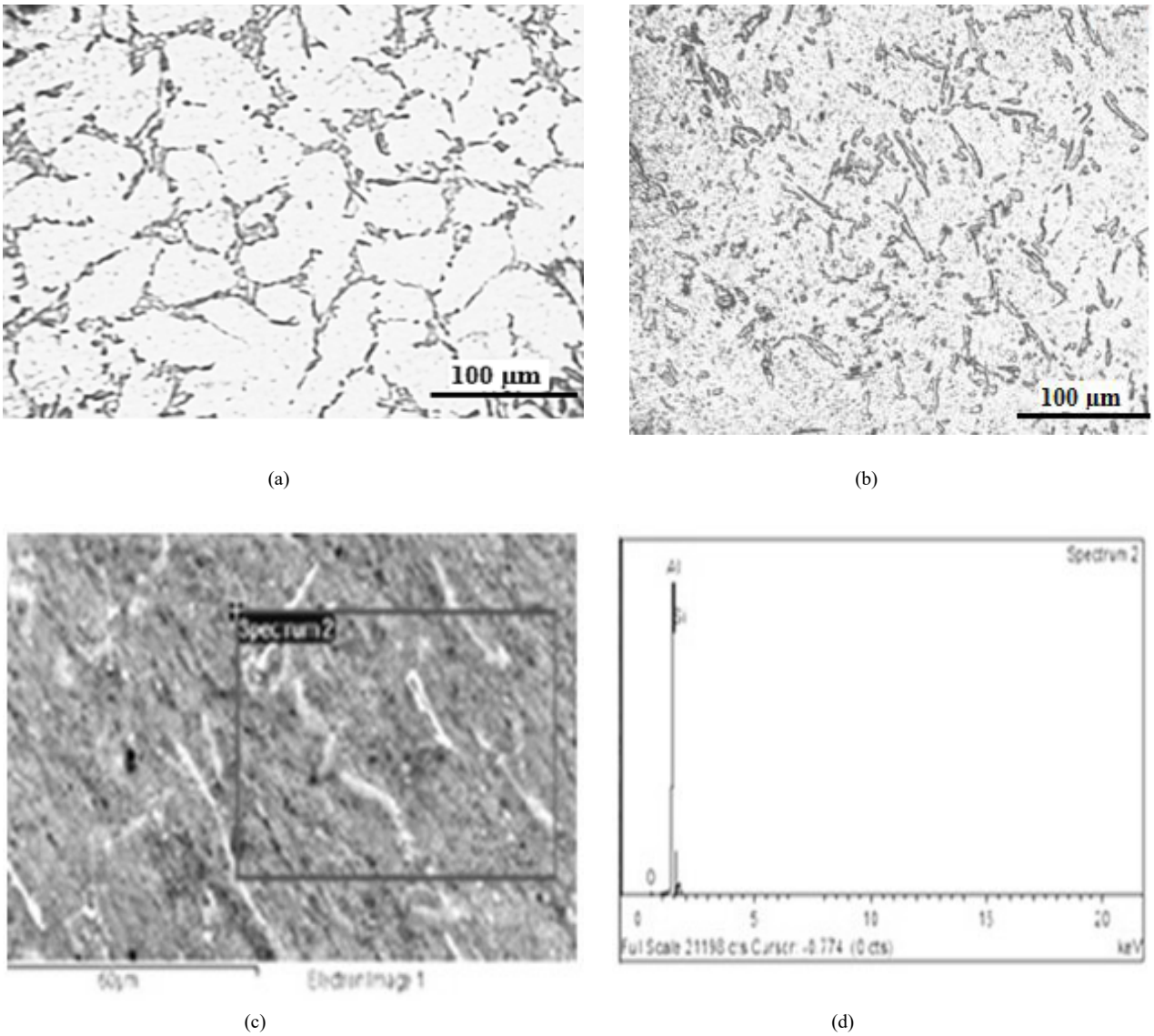


Figure 1. Optical micrograph and SEM analysis of A356 alloy. (a) Optical micrograph of A356 Alloy (b) Optical micrograph of A356 Alloy (c) SEM/EDX analysis of A356 alloy (d)SEM/EDX analysis of A356 alloy

that a non-homogeneous Si tends to connect at inter dendritic grain boundaries. Figures 1(c) and (d) shows the SEM/EDX analysis of A356 alloy. The greatest peak in the EDX pattern indicates that Al is the main ingredient of A356 alloy, while Si is the main alloying element. A tiny O peak is also seen, which could have developed during the casting process.

Figure 2(a) shows the optical micrographs and Figure 2(b) SEM micrographs of A356-SiC MMCs produced at a stirring speed 250 rpm. Micrographs clearly show the SiC particles are agglomerated in A356 matrix at a speed of 250 rpm. The reason behind this agglomeration is due to the insufficient speed of the stirrer and resulted in non-homogeneous distribution of SiC particles in A356 matrix. The optimized stirring time of 7 minutes is used for comparison of results. SiC Particle distribution is seen well in Figures 2(c) and 2(d) as the stirring speed used for producing A356-SiC MMCs is 350 rpm. Figures 2(e) and (f) clearly show the SiC particles have moved away from each other in the matrix due to increased speed at

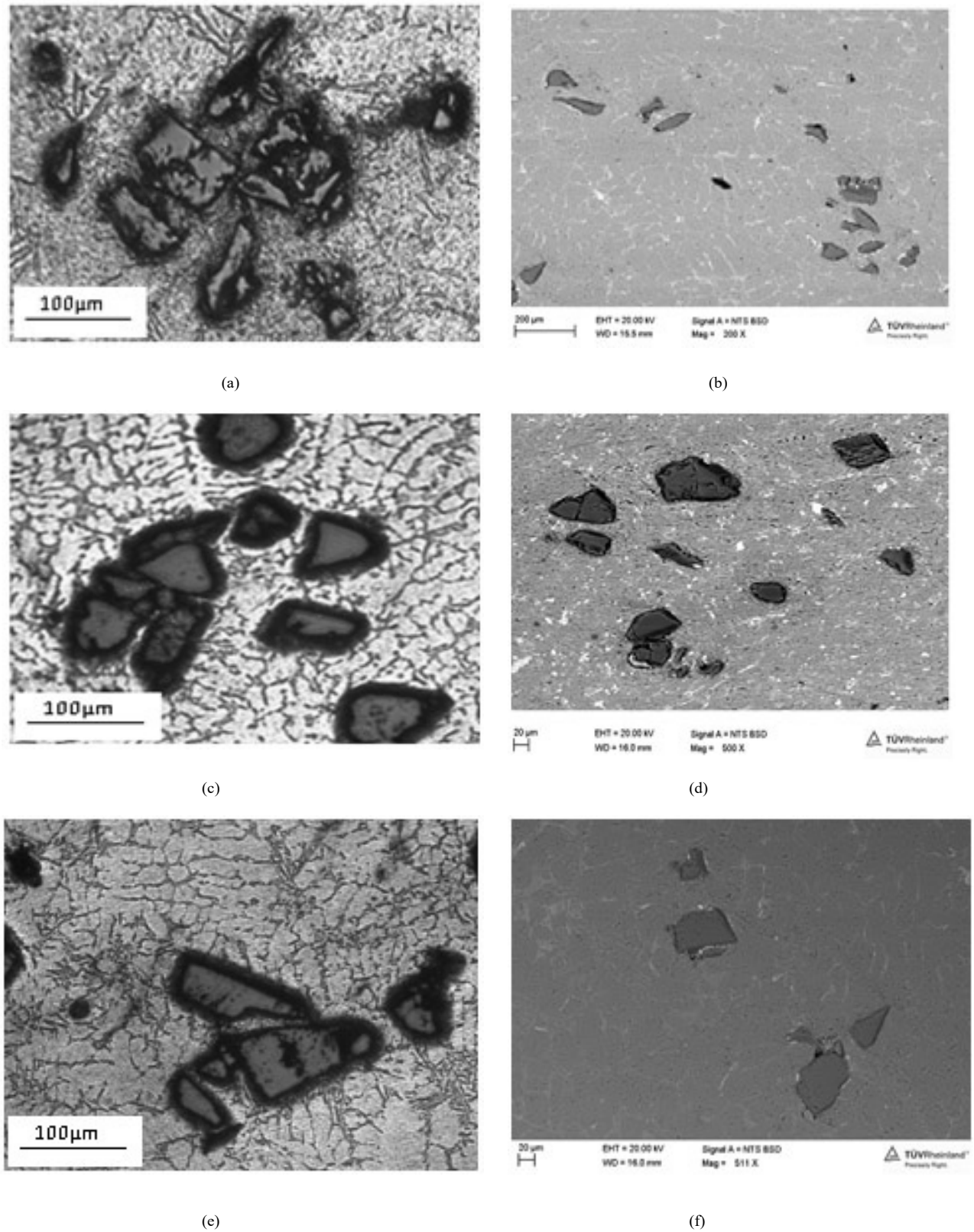


Figure 2. Optical and SEM micrograph of A356 at different stirring speed. (a) Optical micrograph of A356-Sic at 250rpm (b) SEM micrograph of A356-Sic at 250rpm (c) Optical micrograph of A356-Sic at 350rpm (d) SEM micrograph of A356-SiC at 350rpm (e) Optical micrograph of A356-Sic at 450rpm (f) SEM micrograph of A356-Sic at 450rpm

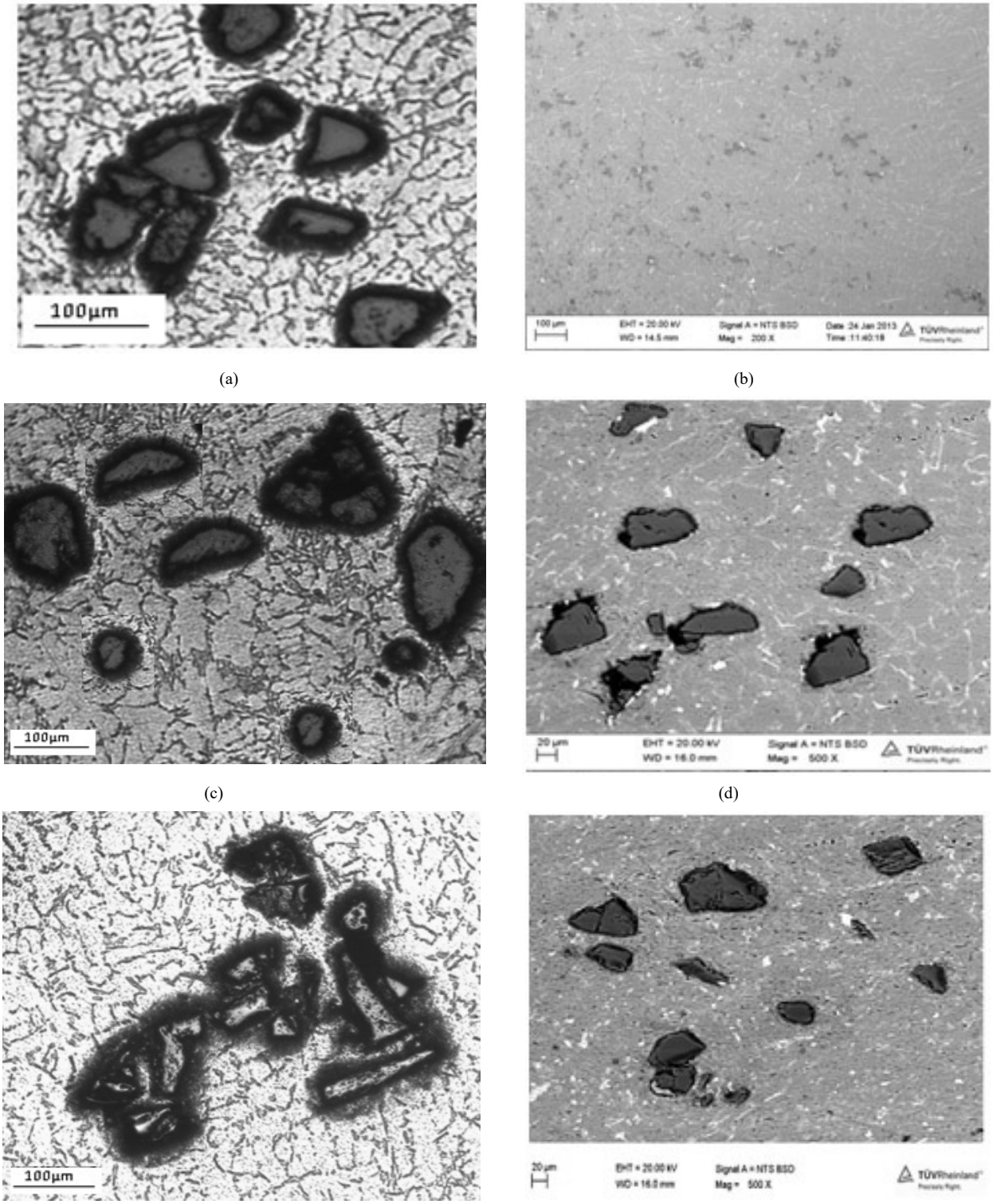
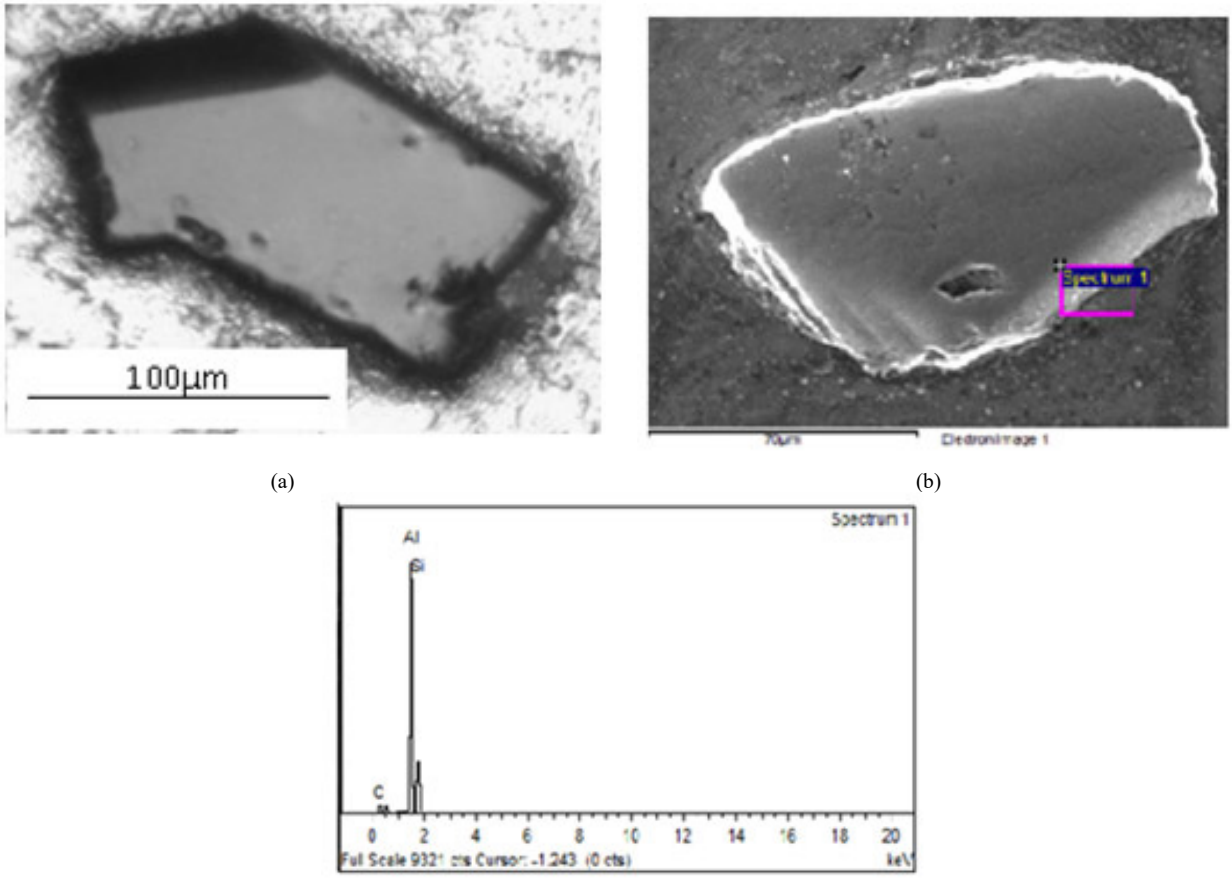


Figure 3. Optical and SEM micrograph of A356 for different stirring time. (a) Optical micrograph of A356-Sic at 5 min stirring time (b) SEM micrograph of A356-Sic at 5 min stirring time (c) Optical micrograph of A356-Sic at 7 min stirring time (d) SEM micrograph of A356-Sic at 7 min stirring time (e) Optical micrograph of A356-Sic at 9 min stirring time (f) SEM micrograph of A356-Sic at 9 min stirring time



(a) (b)

(c)

Figure 4. Optical and SEM micrograph demonstrating excellent bonding between SiC particles and the A356 matrix and its Edx. (a) Optical micrograph demonstrating excellent bonding between SiC particles and the A356 matrix. (b) SEM micrograph demonstrating excellent bonding between SiC particles and the A356 matrix. (c) EDX of SiC particle with A356 matrix

450 rpm. Hence, the speed is optimized to 350 rpm from the obtained micrographs. It is also seen in Figures 3(a), (b) and (c) that a proper stirring with a speed of 350 rpm and at a time of 7 minutes has resulted in a good particle- matrix bonding. The above-mentioned figures show that stirring speed played a significant influence in the homogenous dispersion of SiC particles in the A356 matrix.

Hence it is the evident that the optimized stirring speed found to be 350RPM to obtain a sound A356-SiC MMCs. This has resulted in improved mechanical properties also.

The stirring time were varied as 5, 7, 9 minutes at a constant optimized speed of 350 rpm. Figures 3(a), (c),(e) shows optical photographs of A356-Sic at 5, 7, 9 min stirring time. And Figures 3(b), (d), (f) shows SEM photographs of A356-Sic at 5, 7, 9 min stirring time. 7 min stirring time microstructural photographs it is more evident and consistent distribution of SiC particles is seen as compared to 5, 9 min stirring. Hence 7 min stirring proved to be optimum in producing sound castings.

It is also seen in Figures 4(a) and (b) that at optimum stirring with a speed of 350 rpm and optimum stirring time of 7 minutes resulted in good bonding between particles and matrix. And it is also clear from Figures 2

(a)-(f) and 3(a)-(f) that, as detailed in the next sections, the optimal stirring speed and time were critical in achieving homogenous dispersion of SiC particles in the A356 matrix and hence improved mechanical properties.

3.2 Hardness

It is seen from the Tables 1, 2 and 3 that, hardness of A356 has increased with the addition of SiC particles as SiC being the harder phase increases the hardness of A356-SiC MMCs[13]. In A356-SiC MMCs, there has been

Table 1. Hardness at varying stirring speed and at a constant stirring time of 7 minutes

S. No	Compositions	Stirring speed (rpm)	VHN	Distance from base of the specimen (cm)			
				5	10	15	20
1	A356	-	65	65	64	63	66
3	A356-15SiC MMCs	250	74	71	74	73	71
4	A356-15SiC MMCs	350	84	82	84	84	83
5	A356-15SiC MMCs	450	76	71	75	74	73

Table 2. Mechanical properties at varying stirring speeds and at a constant stirring time of 7 minutes

Sl. No	Compositions	Stirring speeds (rpm)	VHN	UTS Mpa	%Elongation
1	A356	-	65	180	3.50
2	A356-15SiC MMCs	250	74	185	2.5
3	A356-15SiC MMCs	350	84	190	3.0
4	A356-15SiC MMCs	450	76	184	2.00

Table 3. Mechanical properties at varying stirring time and at a constant stirring speed of 350 rpm

S. No	Compositions	Stirring Time (min)	VHN	UTS Mpa	%Elongation
1	A356	-	65	180	3.50
2	A356-15SiC MMCs	5	72	185	2.40
3	A356-15SiC MMCs	7	76	190	2.50
4	A356-15SiC MMCs	9	74	186	2.30

a significant grain refining. Which can also be seen in micro structural studies as shown in Figures 1(a) to 2(f). The hardness value depends on presence of SiC particle and their distribution. Hardness tests are conducted at different locations of the specimen, i.e. at 5, 10, 15, 20 cm distance from base of the specimen. From Tables 2 and 3 it is clear that optimum stirring speed of 350rpm and optimum stirring time of 7 minutes displayed a better hardness values compared to other stirring speeds considered for the study. This clearly indicates uniform distribution of SiC particles at an optimum stirring speed of 350 rpm and at 7 minutes stirring time. The uniform distribution of SiC particles result in improving mechanical properties of the A356-SiC MMCs.

Table 1 shows mechanical hardness, Vicker Hardness Number, of A356 alloy, A356-15SiC MMCs at varying stirring speed and at a constant stirring time of 7 minutes.

Table 2 shows mechanical properties of A356 alloy, A356-15SiC MMCs at varying stirring speeds and at a constant stirring time of 7 minutes.

Table 3 shows mechanical properties of A356 alloy, A356-15SiC MMCs at varying stirring time and at a constant stirring speed of 350 rpm.

3.3 Tensile Strength

It is clear from Table 2 and Table 3 that the the addition of SiC to the A356 alloy boosts its tensile strength. The addition of hard SiC particles, which act as barriers to dislocation motion, is responsible for the increase in tensile strength of A356-SiC. The number of dislocations increases the density of dislocations, which improves the strength of A356-SiC MMCs. Furthermore, the addition of hard SiC particles increased the strength of A356 alloys, resulting in improved tensile strength and resistance to tensile stresses, which can be attributed to the increase in Ultimate tensile strength[24]. As it was observed like hardness, the stirring speed and time played an important role to improve the tensile strength as the optimum values of tensile strength was obtained for 350 RPM and 7 min stirring. When the stirring speed reaches its optimum value (350 RPM) any further increase in stirring parameter depletes the tensile strength. The vortex formed due to higher stirring speeds in the liquid melt might have drawn the air and other gas particles into the melt, ensuring a composite with blow holes or entrapped gases. It can also be noted from Table 2 and 3 that along with tensile strength, % elongation also increases with increase in stirring parameters upto an optimum value and then depletes further with increase in stirring parameters above optimum values.

4.0 Conclusions

Stir casting method was used to make A356-SiC composites, with various stirring parameters such as stirring speed and time. Microstructures and mechanical behaviours were used to investigate the effects of altering stirring speed and time. To improve mechanical qualities, stirring speed and time were optimised based on these factors. The following conclusions were taken from the experimental results.

1. At lower stirring speed and times either the absence of SiC particle or clustering of SiC particles were seen. This in turn results in poor mechanical properties. However, with increase in stirring speed and time upto an optimum value, proper and uniform distribution of SiC particles throughout the matrix were seen and hence uniform properties in all direction. But the uniform distribution of SiC particles depletes with increase in stirring speed and time above the optimum value.
2. Stirring speed of 350 rpm with a stirring time for 7 minutes proves to be optimum in achieving uniform dispersion of SiC particulates and hence uniform and maximized properties in hardness and tensile strength can be achieved.

5.0 Acknowledgement

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6.0 References

1. Charles S, Arunachalam VP. Effect of particle inclusion on the mechanical properties of composites fabricated by liquid metallurgy. Indian J Eng Mater Sci. 2003; 10:301.

2. Nai SML, Gupta M. Influence of stirring speed on the synthesis of Al/SiC based functionally gradient materials. Compos Struct. 2002; 57:227–33. https://doi.org/10.1016/S0263-8223(02)00089-2
3. Hashim J, Looney L, Hashmi MSJ. Metal matrix composites: production by the stir casting method. J Mater Process Technol. 1999; 92/93:1–7. https://doi.org/10.1016/S0924-0136(99)00118-1
4. Golestanipour M, Khadivi Ayask H, Sasani N, Sadeghian MH. A novel, simple and cost effective Al A356/Al2O3 nano-composite manufacturing roucost-effective m distribution of nanoparticles. International Journal of Engineering (IJE), TRANSACTIONS C: Aspects. 2015; 28(9):1320-7. https://doi.org/10.5829/idosi.ije.2015.28.09c.09
5. Kuldeep B, Ravikumar KP, Pradeep S. Effect of h-boron nitrate on microstructure and mechanical behavior of Al7075 metal matrix composite producing by stir casting technique. International Journal of Engineering (IJE), IJE TRANSACTIONS A: Basics. 2019; 32(7):1017-22. https://doi.org/10.5829/ije.2019.32.07a.15
6. Aswad MA, Awad SH, Kaayem AH. Study on iraqi bauxite ceramic reinforced aluminum metal matrix composite synthesized by stir casting. International Journal of Engineering (IJE), IJE TRANSACTIONS A: Basics. 2020; 33(7):1331-9. https://doi.org/10.5829/ije.2020.33.07a.20
7. Hashim J, Looney L, Hashmi MSJ. Particle distribution in cast metal matrix composites, Part 1. J Mater Process Technol. 2002; 123:251–7. https://doi.org/10.1016/S0924-0136(02)00098-5
8. Hashim J, Looney L, Hashmi MSJ. Particle distribution in cast metal matrix composites, Part 11. J Mater Process Technol. 2002; 123:258–63. https://doi.org/10.1016/S0924-0136(02)00099-7
9. Ourdjini A, Chew KC, Khoo BT. Settling of silicon carbide particles in cast metal matrix composite. J Mater Process Technol. 2001; 116:72–6. https://doi.org/10.1016/S0924-0136(01)00843-3
10. Lloyd DJ, Lagace H, Mcleod A, Morris PL. Microstructural aspects of aluminium–silicon carbide particulate composites produced by a casting method. Mater Sci Eng A. 1989; 107:73–80. https://doi.org/10.1016/0921-5093(89)90376-6
11. Naher S, Brabazon D, Looney L. Simulation of the stir casting process. J Mater Process Technol. 2003; 143/144:567–71. https://doi.org/10.1016/S0924-0136(03)00368-6
12. Balasivanandha Prabu S, Karunamoorthy L, Kathiresan S, Mohan B. Influence of stirring speed and time on distribution of particles in cast metal matrix composite. J Journal of Materials Processing Technology. 2006; 171:268–73. https://doi.org/10.1016/j.jmatprotec.2005.06.071
13. Li-na G, Lin G, Hong-wei Z, Lu-jun H. Effects of stirring parameters on microstructure and tensile properties of (ABOw+SiCp)/6061Al composites fabricated by semi-solid stirring technique. Trans Nonferrous Met Soc China. 2011; 21:S274-9. https://doi.org/10.1016/S1003-6326(11)61590-2
14. Zhao Z-Y, Guan R-G, Zhang J-H, Zhao Z-Y, Bai P-K. Effects of process parameters of semisolid stirring on microstructure of Mg–3Sn–1Mn–3SiC (wt%) strip processed by rheo-rolling. Acta Metall Sin (Engl Lett). 2017; 30(1):66–72. https://doi.org/10.1007/s40195-016-0509-8
15. Annigeri UK, Veeresh Kumar GB. Method of stir casting of Aluminum metal matrix Composites: A review. Materials Today: Proceedings. 2017; 4:1140–6. https://doi.org/10.1016/j.matpr.2017.01.130
16. Sozhamannan GG, Balasivanandha Prabu S, Venkatagalapathy VSK. Effect of processing paramters on metal matrix composites: stir casting process. Journal of Surface Engineered Materials and Advanced Technology. 2012; 2:11-5. https://doi.org/10.4236/jsemat.2012.21002
17. Kaushi N, Singhal S. Experimental investigations on microstructural and mechanical behavior of friction stir welded aluminum matrix composite. International Journal of Engineering (IJE), IJE TRANSACTIONS C A: Basics. 2019; 32(1):162-70. https://doi.org/10.5829/ije.2019.32.01a.21
18. Soltani S, Khosroshahi RA, Mousavian RT, Jiang Z-Y, Boostani AF, Brabazon D. Stir casting process for manufacture of Al–SiC composites. Rare Met.
19. Tham LM, Gupta M, Cheng L. Influence of processing parameters during disintegrated melt deposition processing on near net shape synthesis of aluminium based metal matrix composites. Materials Science and Technology. 1999; 15:1139. https://doi.org/10.1179/026708399101505185
20. Zhao Z-Y, Guan R-G, Zhang J-H, Zhao Z-Y, Bai P-K. Effects of process parameters of semisolid stirring on microstructure of Mg–3Sn–1Mn–3SiC (wt%) Strip Processed by Rheo-rolling. Acta Metall Sin (Engl Lett).

2017; 30(1):66–72. https://doi.org/10.1007/s40195-016-0509-8

21. Bindumadhavan PN, Chia TK, Chandrasekaran M, Wah HK, Loh Nee Lam O, Prabhakar. Effect of particle-porosity clusters on tribological behaviour of cast aluminium alloy A356–SiCp metal matrix composites. Mater Sci Eng A. 2001; 315:217–25. https://doi.org/10.1016/S0921-5093(00)01989-4
22. Kori PS, Vanarotti M, Angadi BM, Nagathan VV, Auradi V, Sakri MI. IOP Conf Series: Materials Science and Engineering. 2017; 225:012265. https://doi.org/10.1088/1757-899X/225/1/012265
23. Vanarotti M, Shrishail P, Sridhar BR, Venkateswarlu K, Kori SA. Study of mechanical properties and residual stresses on post wear samples of A356-SiC metal matrix composites. Procedia Materials Science. 2014; 5:873-82. https://doi.org/10.1016/j.mspro.2014.07.374
24. Kato K. Wear in relation to friction- A review. Wear. 2000; 241, 2000:151–7. https://doi.org/10.1016/S0043-1648(00)00382-3in