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SYNTHESIS A380 ALUMINUM COMPOSITE REINFORCED WITH NBC TROUGH STIR CASTING METHOD

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ABSTRACT

Aluminum matrix composite has widely used in the automotive and aerospace industry due to its attractive characteristics. Many metal carbides have been used to improve strength and hardness. Nevertheless, NbC as reinforcement has been little explored in the literature. The aim of this work is to use the stir casting method to produce aluminum matrix composite reinforced with three different NbC fractions (5 wt%, 10 wt%, and 15 wt%). A stirring mechanism was developed with controlled stirrer angle, speed, and agitation time. A380 aluminum alloy was melted at 750°C and 200°C pre-heated Mg to act as a wetting agent, and NbC was added to the alloy. The composite was mixed at 400 rpm for 5 min and then poured into a pre-heated 200°C steel mold. Microstructural analysis was carried out in a scanning electron microscope and optical microscope. The results show that stir casting is an excellent method for making a composite. A 39% additional reduction in grain size was obtained with 10% NbC. Hardness was increased with the NbC as reinforcement, as well.

Keywords: *A380, grain refiner, stir casting, niobium carbide, composite.*

INTRODUCTION

Reinforcement particles are utilized to provide better mechanical and wear properties to composites. Niobium carbide (NbC) is a good material for reinforcement. Higher formability, weldability, toughness, and strength behaviors could be highlighted among its properties. NbC provides excellent high hardness, allowing good thermal defiance [(1)]. Between the composites, aluminum-based matrix composite is widely used in the automobile, aerospace, marine, chemical, and transportation industries [(2)]. Due to the excellent castability, low thermal expansion coefficient, and high strength/weight ratio, A380 is the most utilized hypoeutectic Al-Si alloy in the automotive industry [(3)]. Stir casting is one of the most efficient and economical techniques for producing composites. It provides a good dispersion of particles and has a lot of parameters, which can be changed to increase the properties of the composite [(4)].

Some materials can be added to increase the composite performance. A good wettability between reinforcement and matrix is essential to increase the mechanical properties. The most common is magnesium (Mg) which reacts with the particle surface oxides, improving the superficial energy of the dispersoid and decreasing the solid-liquid tension, inducing a better wettability with the molten aluminum[(5).] The morphology and size of eutectic silicon significantly affect mechanical properties. Making a change to a fibrous-like shape of eutectic strontium (Sr) is one of the best modifier agents [(6)].

In order to understand the formation and microstructural properties of the A380/NbC composite, the aim of this study is to synthesize an aluminum matrix composite (AMC) with NbC as reinforcement in three concentrations (5 wt. %, 10 wt. % and 15 wt. %) through the stir casting method.

MATERIALS AND METHODS

A380 aluminum alloy was selected from a commercial recycled alloy as a matrix material, and the chemical composition is shown in Table 1 . The reinforcement was given by CBMM, the NbC powder with an average size of 1.2 µm.

Table 1:Chemical composition of A380 aluminum alloy (wt. %).

Alloy	**Si**	**Fe**	**Cu**	**Mn**	**Mg**	**Zn**	**Ni**	**Cr**	**Pb**	**Ti**	**Ca**
SAE 380	8,159	0,786	3,281	0,139	0,068	2,961	0,197	0,017	0,183	0,082	0,002

A forced Air-Drying Oven is utilized to pre-heat cylindrical permanent molds, Mg, slag remove agent (Covermax), degassing (Neutrogás) and NbC at 200 °c for 1h. This step is essential to remove the layers of gas and unwanted impurities [(7)]. Aluminum was melting in a 35 KW GRION induction furnace at 750 °C. The stir casting setup is shown in Figure 1.

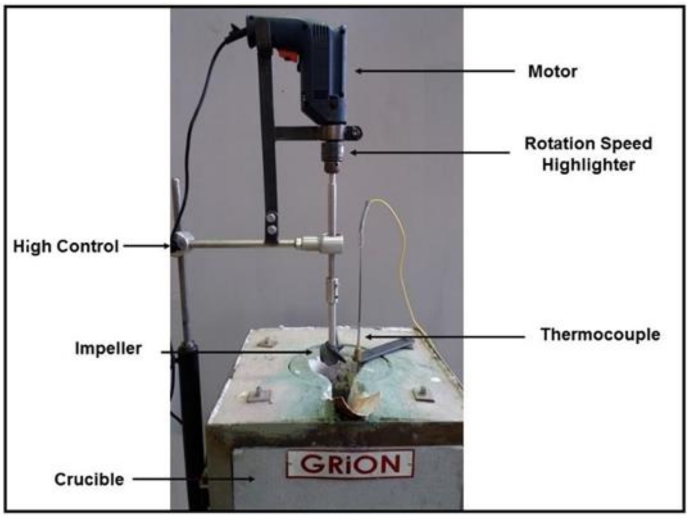

Figure 1: Developed stir casting setup

The reinforcement and humectant agent are covered in packages from aluminum foils. This procedure was realized to prevent material loss during the addition. [(7)]. The stir casting was developed to possible high control, time, velocity, blade angle (changed it), and accurate temperature control. A four-blade impeller with an angle of 30 ° was made of stainless steel 304. To prevent blade wear and possible contamination of the composite, the impeller was coated with Carbide tungsten-based (WC-10Co-4Cr) by HVOF in the Brazil OPT company.

A sequence of products is added to the molten in the following order: first Sr, Mg chips, grain refiner Al-5Ti-1B tracking by scorifier and desgasefier and finally, the NbC powder was put in the crucible. A continuous vigorous stirring was carried out at 400 rpm for 5 min to homogenize the particle distribution. Blade angle[(8)], Stirring speed[(9)], and time[(7)] parameters were from literature and as well as several preliminary tests. Then immediately, the AMC was poured into pre-heat cylindrical permanent molds with 31 mm diameter and 250 mm height. It can be seen in Table 2 the configuration of cast composites.

Table 2: Casting conditions (wt%).

Samples	A380	Sr	Mg	Al-5Ti-1B	Degassing	Slag agent	NbC
Al0NbC	98,075	0,025	1	0,2	0,3	0,4	0
Al5NbC	93,075	0,025	1	0,2	0,3	0,4	5
Al10NbC	88,075	0,025	1	0,2	0,3	0,4	10
Al15NbC	83,075	0,025	1	0,2	0,3	0,4	15

Casting samples were machined until 25 mm and then sectioned in pieces of 5 mm high, and a quarter cut was made in the circular samples to mount. Specimens were grinding in the sequence 220, 400, 600, and 1200 mesh, followed by two diamonds suspension of 3 µm and 0.25 µm, and final vibratory polishing with 0.04 µm silica suspension Vibromet 2.
Microstructure characterization was made in the optical microscope and scanning electron microscope (SEM) Tescan Vega 3. No etch is performed to investigate the standard samples' microstructure. The images were utilized to analyze in the ImageJ open software. To determine grain size, an electrolytic etch was made with fluoboric acid in a concentration of 6 % in 25 V for 150s.
Rockwell B hardness test (HRB) was performed in a Rockwell test machine PANTEC RBS. A spherical indenter of 1,5875 mm, with 10 kg of pre-load and load of 100 kgf, was utilized. A simple average was made from 10 indentions to obtain the final value.

RESULTS AND DISCUSSION

This section will show the results and discussions from NbC powder characterization, metallographic analysis and hardness test of the composites.

Powder Characterization

Backscattered images (BSE) of NbC powder are shown in Figure 2 (A). The almost equiaxial morphology with respective chemical composition from the EDS map can be seen. In the minerals tighter with Nb, tantalum (Ta) can achieve a high Nb affinity (10). Further, the refining process possible not eliminate all the particles of this element, showing a small amount in the EDS composition, as shown in Figure 2 (B).
In Figure 2 (C), an average size of 1.2 µm has resulted from the ImageJ analysis of 5 images. The SEM measurements agree with these results. To confirm the results, The SEM's software was used to directly measure the particles' size with results according to ImageJ analysis.

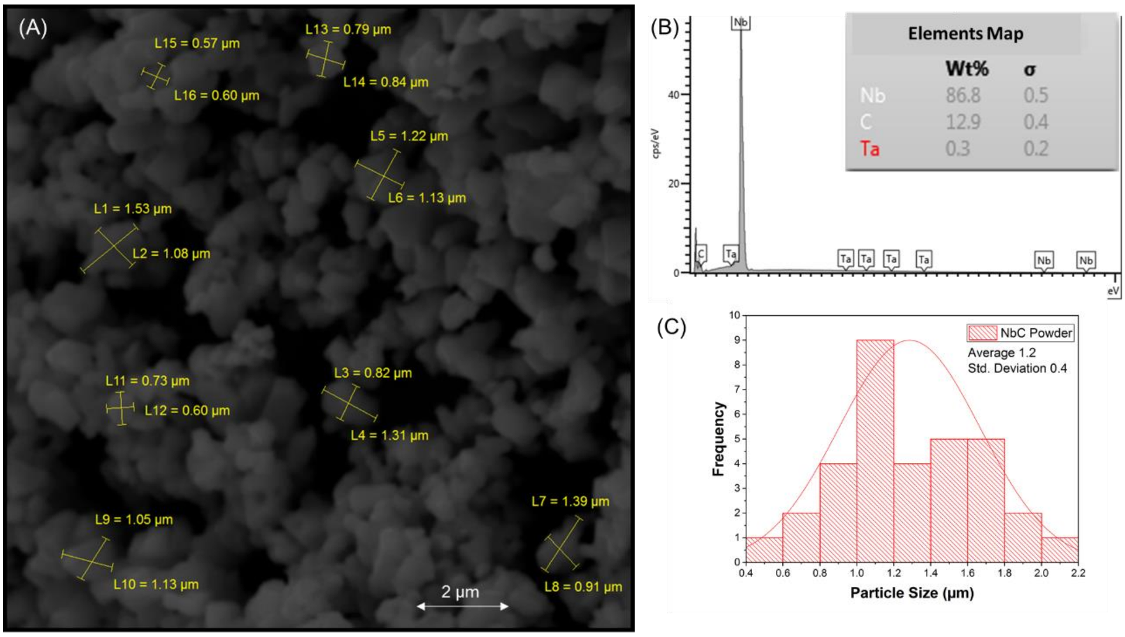

Figure 2: (A)Backscattered electron MEV image from NbC powder respective chemical composition from EDS (B) and particle size from ImageJ analysis (C).

Metallographic Analysis

From Figure 3, the composite shows a typical microstructure of A380 aluminum alloy phases. A majority formation of Al-α, Acicular needle-like shaped Fe-β [(6)]. And circular-like formations of Cu-Ɵ [(3)]. Around the Al-α phase is the eutectic Al/Si in a fibrous shape formation modified by Sr [(11)].

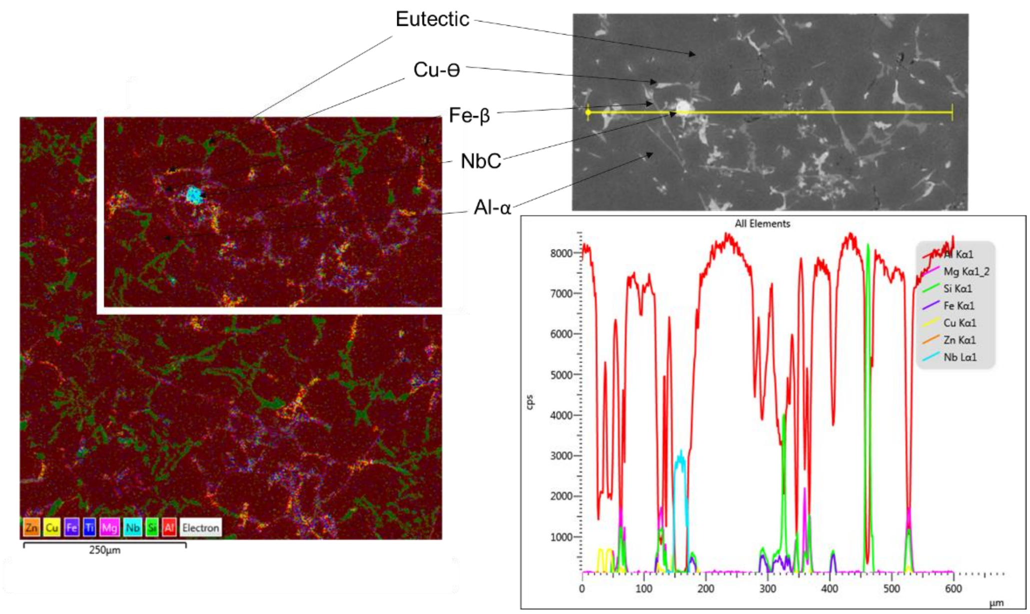

Figure 3: EDS map and line scan of Al5NbC composite with marked formations

In the morphological analysis of the sample Al0NbC, Figure 4 (A), more dendritic formations can be founded. As long as the wt% of reinforcement increases, a tendency to more equiaxed formations is noted, as shown in Figure 4 (B). Moreover, the particles of NbC can change grain growth. In literature [(2)], its modification is also noticed, probably caused by the conjunct action of the grain refiner, stirring process, and the particles.

Figures 4 (E), (F), and (G) show the distribution of NbC most in the eutectic phase, probably due to the final liquid phase.

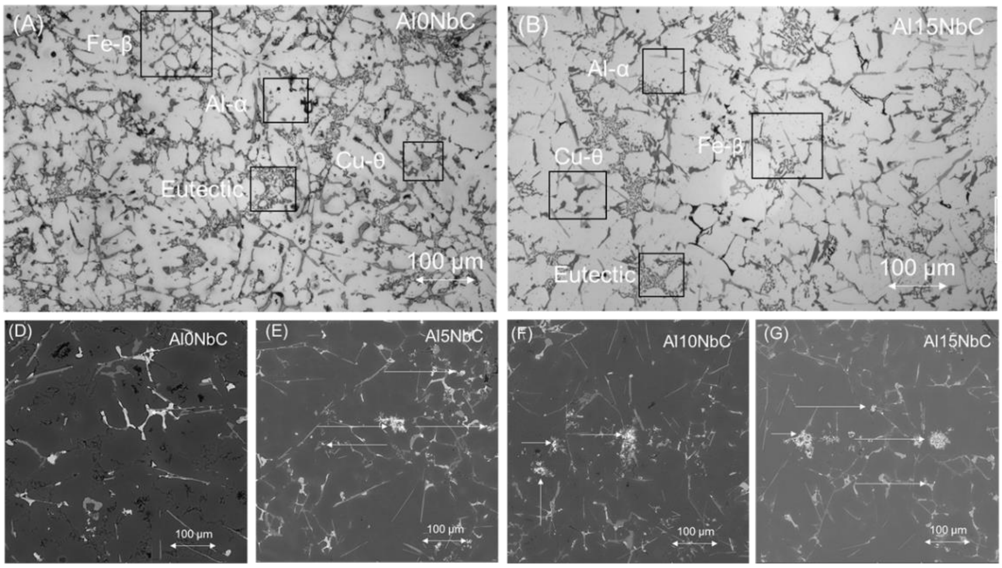

Figure 4: Microstructure of the composites showing the phases (A) Al0NbC (B) Al15NbC, BSE MEV images showing the NbC particles, denoted by white arrows Al0NbC (D), Al5NbC (E), Al10NbC (F) and Al15NbC (G).

There was a relatively good distribution of NbC in all conditions of composites. On the other hand, in Figure 4 (E), (F), and (G), it also can be discerned some clusters in all conditions. Homogenously distribution is linked to solidification rates. When the particles are added, an increase in its wt% decrease the cooling rates. Particles can be rejected to the freezing front or engulfed by this. Solidification rates influence the form of distribution in the final ingot [12].

Grain Size and Hardness

Polarized light micrographs of samples were utilized to measure grain size through Heyn's intercept method by ASTM-E112. With the increase in NbC particles, the average grain size was reduced. The results show Al0NbC 233 µm ± 5.0, Al5NbC 174 µm ± 7.0, Al10NbC 143 µm ± 2 and Al15NbC 144 µm ± 4. The grain refiner and stirring combination provide a great grain reduction to unrefined alloy [6]. However, an additional 39% reduction was obtained with 10% NbC. From the literature, a grain size reduction is also noticed with an increase in the reinforced amount [13].
An increase in hardness values is also founded on an increase in the NbC addition. The unreinforced material shows the lowest value, 35.1 HRB ± 3.2, and Al15NbC 55.45 HRB ± 3.5. Nevertheless, a slight difference was noted between the reinforcement, with Al5NbC 51.50 HRB ± 2 and Al10NbC 54.45 HRB ± 1.9. In the literature [9], an increase in the hardness with reinforcement addition was also noticed, generally due to the presence of hard particles, in the limitation of plastic deformation.

CONCLUSIONS

This study successfully reinforced an A380 aluminum alloy with NbC particles. The typical microstructure of cast aluminum was found with fibrous-shape eutectic from Sr modifier. The NbC was almost homogenously distributed in the matrix, showing an average reduction in grain size and an increase in hardness after the reinforcement addition. The 10 % of NbC was the best option among the conditions analyzed.

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REFERENCES

1. VIJAYA, J. D.; KUMAR, J. P.; SMART, D. S. R. Analysis of hybrid aluminium composite material reinforced with Ti and NbC nanoparticles processed through stir casting. Materials Today: Proceedings, CMAE'21. v. 51, p. 561–570, 2022.
2. SETHI, D.; KUMAR, S.; CHOUDHURY, S.; SHEKHAR, S.; SAHA ROY, B. Synthesis and characterization of AA7075/TiB2 aluminum matrix composite formed through stir casting method. Materials Today: Proceedings, v. 26, p. 1908–1913, 2020.
3. IRIZALP, S. G.; SAKLAKOGLU, N. Effect of Fe-rich intermetallics on the microstructure and mechanical properties of thixoformed A380 aluminum alloy. Engineering Science and Technology, an International Journal, v. 17, n. 2, p. 58–62, 2014.
4. GARG, P.; JAMWAL, A.; KUMAR, D.; et al. Advance research progresses in aluminium matrix composites: manufacturing & applications. Journal of Materials Research and Technology, v. 8, n. 5, p. 4924–4939, 2019.
5. PAI, B. C.; RAMANI, G.; PILLAI, R. M.; SATYANARAYANA, K. G. Role of magnesium in cast aluminium alloy matrix composites. Journal of Materials Science, v. 30, n. 8, p. 1903–1911, 1995.
6. FERREIRA, J. P. G. Estudo Microestrutural E Reológico da Liga Reciclada de Alumínio A380 Modificada pela Adição de Estrôncio, 2017. 104 f. Dissertação (Mestrado em Engenharia Mecânica), Universidade Tecnológica Federal do Paraná, Ponta Grossa, 2017.
7. HADAD, M.; BABAZADE, A.; SAFARABADI, M. Investigation and comparison of the effect of graphene nanoplates and carbon nanotubes on the improvement of mechanical properties in the stir casting process of aluminum matrix nanocomposites. The International Journal of Advanced Manufacturing Technology, v. 109, n. 9, p. 2535–2547, 2020.
8. MEHTA, V. R.; SUTARIA, M. P. Investigation on the Effect of Stirring Process Parameters on the Dispersion of SiC Particles Inside Melting Crucible. Metals and Materials International, v. 27, n. 8, p. 2989–3002, 2020.
9. RAJU, H. P.; REDDY, M. S. P. Effect of Stirring Speed and Stirring Time on Distribution of Nano Al 2 O 3 Particles in Al7075 Metal Matrix Composite. Asian Journal of Engineering and Applied Technology, v. 8, n. 2, p. 86–89, 2019.
10. SHIKIKA, A.; SETHURAJAN, M.; MUVUNDJA, F.; MUGUMAODERHA, M. C.; GAYDARDZHIEV, S. A review on extractive metallurgy of tantalum and niobium. Hydrometallurgy, v. 198, p. 105496, 2020.
11. ZULFIA, A.; PUTRIANA, L. T. Effect of strontium on the microstructure and mechanical properties of aluminium adc12/nano-sic composite with al-5tib grain refiner by stir casting method. Materials Research Express, v. 6, n. 7, p. 74002, 2019.
12. RAJ, R.; THAKUR, D. G. Influence of boron carbide content on the microstructure, tensile strength and fracture behavior of boron carbide reinforced aluminum metal matrix composites. Materials Science & Engineering Technology, v. 49, n. 9, p. 1068–1080, 2018.

13. HEDAYATIAN, M.; VAHEDI, K.; NEZAMABADI, A.; MOMENI, A. Microstructural and Mechanical Behavior of Al6061-Graphene Oxide Nanocomposites. Metals and Materials International, v. 26, n. 6, p. 1–13, 2019.