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Mechanical properties as a function of casting process of aluminum–silicon alloy matrix composites

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Abstract

Applying aluminum composite in the defense, aerospace and automotive industries depends on how they behave during the elasto-plastic form change. In addition to the factors responsible for changing the form of the alloy, many other factors have an impact on the behavior of the composite form change. In this study, the effect of casting type on the mechanical properties of Al-Si nano composites has been investigated. Due to the proper distribution of reinforcing particles, tensile strength in compo casting sample in semi-solid state is higher than sand casting and squeeze casting. In all samples, the tensile strength of the heat-treated samples has increased by

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about 30%. Tensile strength in compo casting sample in semi-solid state was obtained with higher nano particle reinforcing particles, which can be explained by the fact that the percentage of elongation in micro samples was lower than that of nano composite samples.

Key words: tensile strength, silicon, semi-solid and nano

Introduction:

In addition to the factors responsible for changing the form of the alloy, many other factors have impacts on the behavior of the composite form change. These factors generally include [1-7]:

1. Behavior of the shape change of each component, such as field alloy and reinforcement phase;
2. Microstructural characteristics;
3. Characteristics of the interconnected phase between the reinforcing phase and the alloy of the field, such as the reaction zone product, the sediment and the type of connection;
4. Shape, size, distribution and volume fraction of the reinforcing phase;

5. Physical properties, such as the coefficient of thermal expansion of each component.

Assuming complete connection and uniform distribution of particles, and ineffectiveness of changing the shape of the matrix and reinforcing phases on each other, the simplest way to predict the behavior of the composition of the composite is the classic law of the mixtures[8, 9]. But in most cases, the strength and formulation obtained from empirical calculations is significantly lower than the values obtained from the mixing rule. There are several reasons for this, including the following:

- Influence of elastic and plastic behavioral and reinforcing phases on each other;
- Each component, when placed in a poly phase, exhibits different behaviors;
- Existence of thermal incompatibility stress due to differences in thermal expansion coefficients between field phase and reinforcing phase;
- Inefficient transmission of loads between phases due to the relatively weak connection;
- The presence of imperfections on the reinforcing phase;
- Clustering particles

The density of dislocations in the field increases due to the thermal incompatibility stress, which increases the strength of the field, and, as a result, composites. But many of the factors reduce the stress on composite materials (compared to the mixing rule)[10-14]. Therefore, depending on the overall effect of all the factors involved, the behavior of the composite form change will be different. This non-conformance stress also depends on the temperature at which the composite cools [15-17]. It should be borne in mind that although the thermal inconsistency stress will increase the strength, this increase is not very high in composite particles. The clustering of particles and the presence of imperfections due to the presence of particles are among the factors influencing this issue [18-22].

The main strengths of the nano composites include the strength of the Orowan, the strength due to thinning, the strength of the solid solution, and the strength of the dislocation [23-27]. The linear summation of these phrases can be used to predict the yield stress, and the result will appear as follows.

$$\sigma_{\text{composite}} = \Delta\sigma_{\text{Orowan}} + \Delta\sigma_{\text{grain}} + \Delta\sigma_{\text{solution}} + \Delta\sigma_{\text{dislocation}} \quad (1)$$

Orowan strengthening mechanism results from collision of dislocated and diffused particles. When the composite tolerates the load, plastic form change occurs in the material [28-30]. Nano-size and hard ceramic particles act as obstacles to near-particle and in-situ dislocations [31-33]. This strength factor increases with increasing ceramic phase volume fraction. The following statement is used to express the Orowan mechanism:

$$\Delta\sigma_{\text{Orowan}} = \frac{2Gb}{2\pi(1-\nu)^{1/2}} \frac{1}{\lambda} \ln(D/b) \quad (2)$$

where G is the shear field modulus, b the Burgers vector, ν is the Poisson ratio, λ is the distance between particles, and D is the average diameter of the particles[34-37]. The distance between particles (λ) can be replaced by the volume fraction (V_f) and average particle diameter by the following equation[38, 39]:

$$\lambda = D \left(\frac{\pi}{6V_f} - \frac{2}{3} \right)^{1/2} \quad (3)$$

The second phase particles also act as non-homogeneous nucleation catalyst for the aluminum matrix. This strengthening effect increases by increasing the volume fraction and decreasing the particle size in a constant volume.

Using the Hall-Petch equation, the fine-graining strength effect can be defined as follows [40-43]:

$$\sigma_{\text{grain}} = \sigma_0 + kd^{-1/2} \quad (4)$$

Here σ_{grain} is the contribution of the grains to the yield stress, σ_0 is the friction coefficient, d is the diameter of the grain and k is constant[44, 45].

Therefore, the strength of the resulting fine-grained material can be obtained by the following equation in the nano sized composites:

$$\Delta\sigma_{\text{grain}} = k(d_1^{-1/2} - d_2^{-1/2}) \quad (5)$$

In the case of dissolved atom with a very different size in the field, there is a type of disproportionate strain region around the atom, which in colliding with dislocation can act as barrier to its movement [46-49]. The analysis of the collision between dislocations and the strain field of these particles can be represented by the following equation:

$$\Delta\sigma_{\text{solution}} = G\varepsilon\sqrt{x_f/4} \quad (6)$$

Here G is the elastic shear modulus, x_f is the fraction of the external atoms concentration, and ε is the fraction of the difference between the atoms and the atoms dissolved in the diameters[50, 51].

Because of the difference in the thermal expansion coefficient of the field phase and the reinforcing phase, dislocations occur in the matrix during freezing[52, 53]. Higher dislocation density increases the strength of the field. Factors such as thermal expansion coefficient, particle size and volume fraction, and strength of the field are effective in producing dislocation. The effect of the strengthening dislocations in nano composites can be expressed by the following equation [54-56]:

$$\Delta\sigma_{\text{dislocation}} = AGb\sqrt{\Delta\rho} \quad (7)$$

Here, A is the total surface area of the particles, G is the shear modulus of the field, b the Burgers vector, $\Delta\rho$ is the increase in the density of dislocations in the field due to the presence of particles[57, 58]. In this study, the effect of casting type on the mechanical properties of A356-Al₂O₃ nano-composites will be investigated.

Research Method

Aluminum was used as a metal matrix composite material from A356 alloy with 7% Si and 0.3% Mg. Alumina powder with different dimensions and percentage by weight was used as secondary composite phase particles. In

the step model, the melting of the alloy was carried out in a resistance furnace and in a graphite crucible, and the discharge temperature was considered to be 720 ° C. After degassing with flux and loading the reinforcing particles at 720 ° C, the melt was added to the melt and mixed. Then the melt was poured into the sand mold, and at the end, the model and the power were taken out of the mold and separated.

A rectangular cube was used for compo casting with a squeeze casting technique. About 1 kg of melt was required at each pouring. Alloy melting was carried out in a resistance furnace and in a graphite crucible and the temperature was considered to be about 720 ° C. After degassing with flux and melting at 720 ° C, the reinforcing particles were added to the melt. When the mixture reached the desired temperature, it was poured into a metal stainless steel, and immediately pushed by a weighbridge. At the end, the model was removed from the mold and the center of the model was examined. In this study, an electromagnetic stirrer was used to determine the best distribution of particles. For the melting and preparation of the melt required for use in an electromagnetic stirrer, 1 kg melt was placed inside a graphite crucible and the crucible was transferred to the resistance furnace with its charge. The furnace temperature was adjusted to 720 ° C. After reaching this temperature, and after about half an hour, the crucible was

removed from the furnace and a small amount of covering flux was deposited on the melt and the melt was mixed with a spoon. After deslagging, the secondary composite phase were thrown into the melt and mixed. The melt was then poured from the inside of the graphite crucible into a stainless steel cylindrical mold in the middle of the stirrer, and then the stirrer, pre-adjusted, was simultaneously switched on. During the mixing, a thermocouple was placed in the center. The semi-solid mixture was then transferred into a small rectangular mold made of stainless steel, and pressed with a weighbridge.

In this study, in order to obtain spherical silicones as well as artificial aging, and to obtain proper properties, T6 heat treatment was performed on the samples. For metallography, the samples were first cut to the desired size and then mounted. In order to investigate the microstructure, surface preparation of samples was performed, using sand blast, diamond paste and alumina powder of 0.5 micron and etching in chlorine solution for 10, 20 and 30 seconds. The reason for doing etching in different times is different surface energy of the samples. Tensile test was performed to study the tensile strength of the samples. Samples were made using a lathe machine, according to ASTM B557M (2010) standard, as shown in Fig. 1.



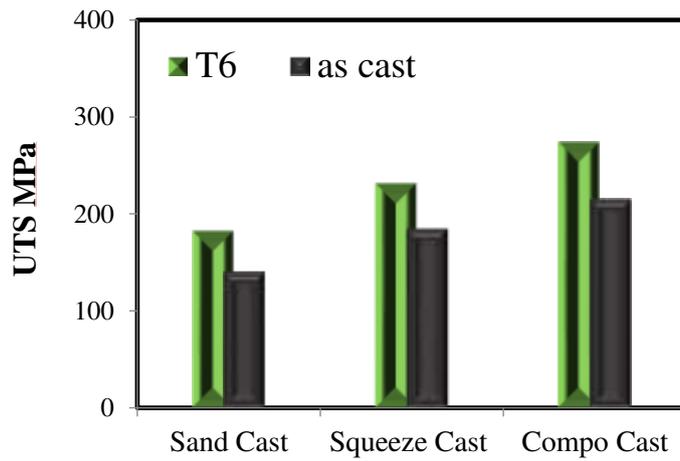
Fig 1: Compo cast model (a) and tensile test sample (b)

Results and discussion:

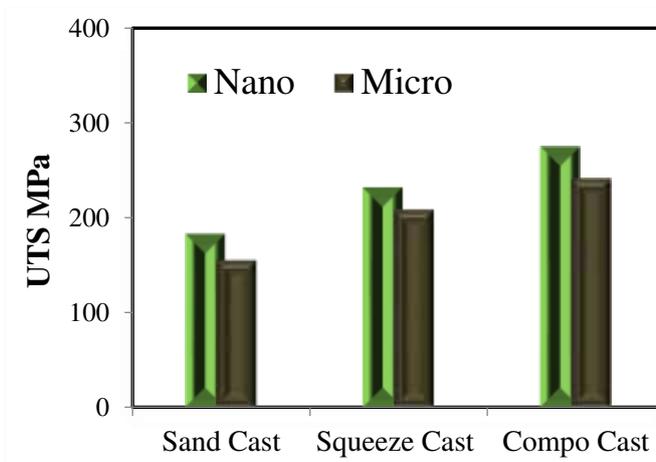
Figure 2A shows the results of the tensile test for different casting samples in both in situ casting and heat treatment. As shown in the figure, the tensile strength in the compo casting sample in semi-solid state is higher than the other two samples. Considering the microstructural results obtained in previous discussions and the proper distribution of reinforcing particles in

the samples of the model presented in this project and the absence of large intermetallic particles, these results appear to be evident. Also, in all samples, the tensile strength of the thermal samples has increased by about 30%. The reason for this increase in tensile strength can be found in the following three factors:

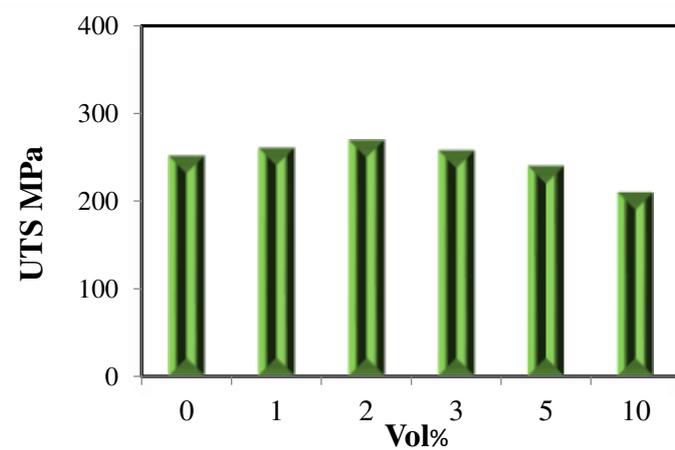
- Removal of residual tensions
- Spheroidization of silicons
- The deposition of the GP regions and Θ from the Mg_2Si phase in the α phase



A



B

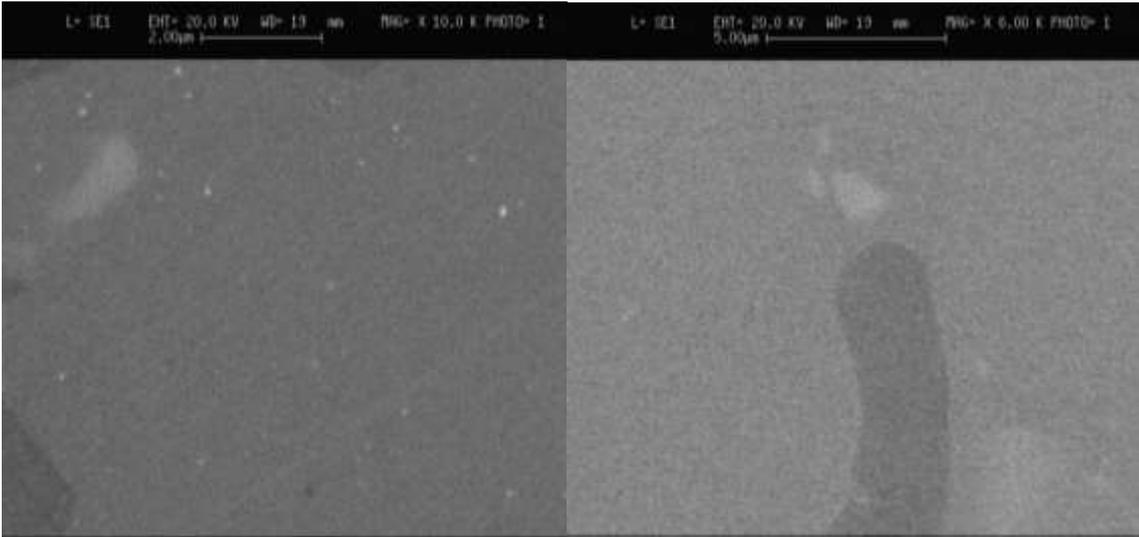


C

Figure 2: Tensile strength chart A: under different casting conditions

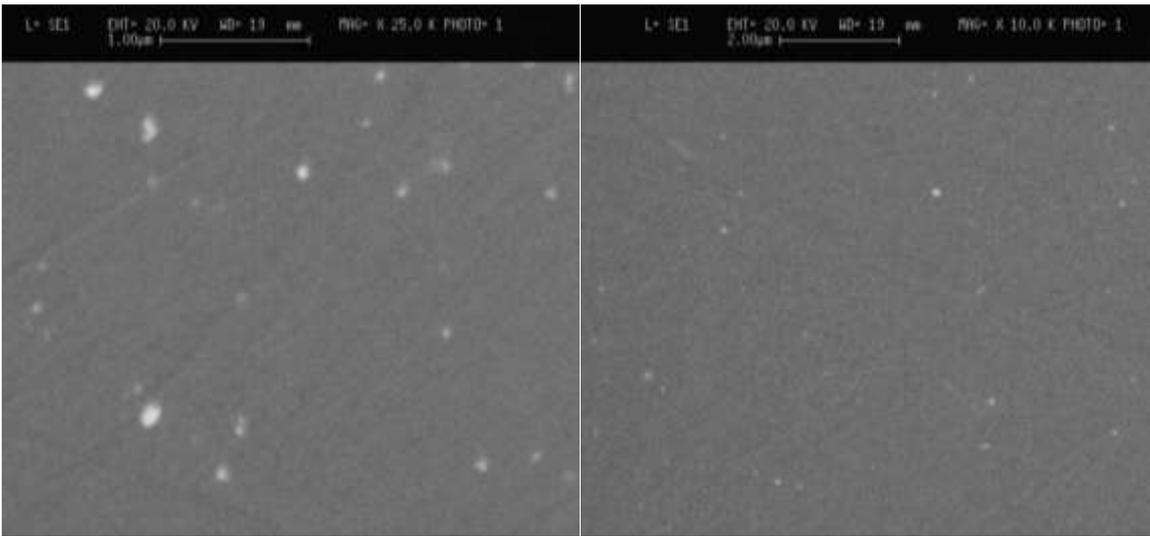
B: size and C: different percentages of reinforcing particles

In Fig. 2B, the tensile strength results are shown for two samples with different reinforcing particle sizes. As shown in the figure, the tensile strength in compo casting sample in semi-solid state is higher with reinforcing nano particles, which can be attributed to the reduction in the percentage of elongation in micro samples compared to nano composite samples. Figure 2C shows the results of tensile strength, and Figure 3 shows SEM image of the microstructure of the same samples in different percentages of the reinforcing particles in compo casting samples in semi-solid state. As shown in composite samples with 1, 2, and 3% reinforcing particles, the reinforcing particles are well distributed in the field. Also in composite samples with a 10% reinforcing particles, there is a relatively well distribution in the field. But the percentage of agglomeration and porosity has increased, which caused the mechanical properties to drop in the samples.



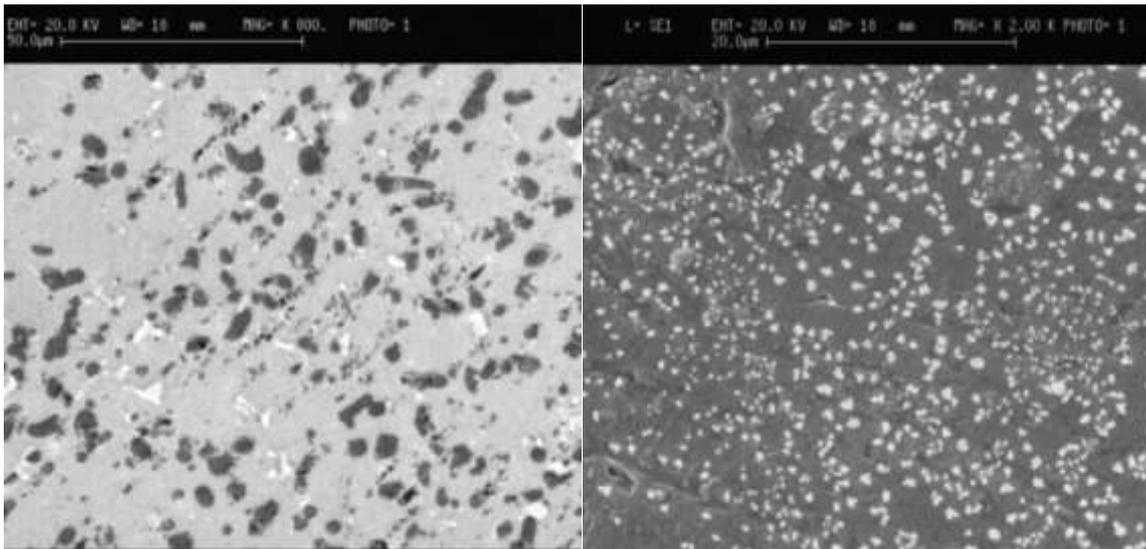
B

A



D

C



F

E

Figure 3 SEM image of the percentages of A: 0 B: 1 C: 2 D: 3 E:
10 (nano) and F:10 (micro) reinforcing particles

A relatively small difference in the ultimate tensile strength is observed between the reinforced and non-reinforced samples, but the yield stress in the reinforced samples is much higher than that of non-reinforced ones. Figure 4 shows the yield stress diagram in the reinforced samples with alumina particles and compares them with the yield stress in the non-reinforced samples. The reason for the high variation in yield stress among the reinforced and non-reinforced samples is alumina nano particles. At the time of tension, these particles block the movement of dislocations and increase the work hardening. Also, the difference in the yield stress in reinforced and non-reinforced samples in the compo casting sample in semi

solid state is more than other samples. The reason for this higher difference is the better distribution of nano particles in the sample model presented in this project and the agglomeration of most of the reinforcing particles, which are supposed to prevent the movement of dislocations and increase the work hardening, squeeze casting and sand casting in reinforced and non-reinforced samples. As a result of the spheroidization of the α_s , and the fact that they are becoming smaller, which is another mechanism of work hardening in nano composites, the yield stress in compo casting samples in semi-soled state has increased more than that in compo casting samples in the form of squeeze casting and sand casting.

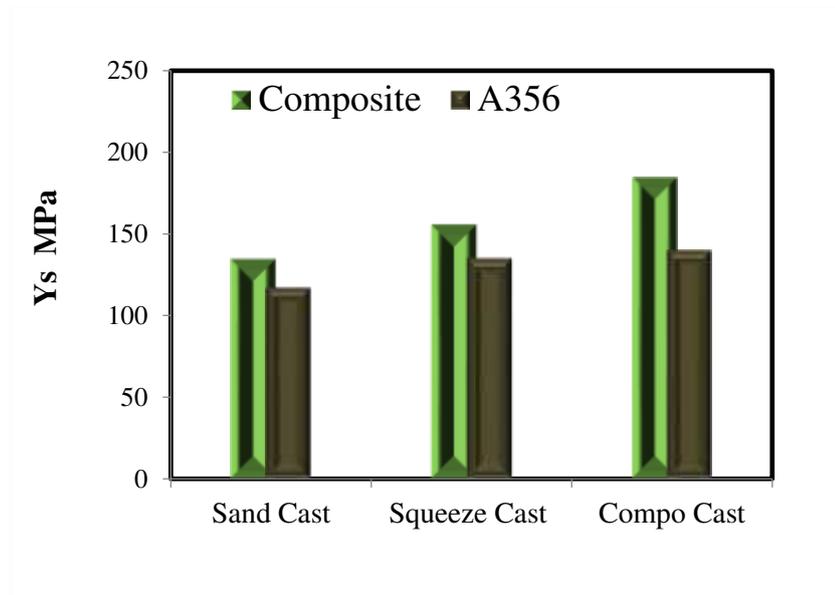


Figure 4: tensile stress diagram in different casting conditions

Figure 5 shows the elongation in cast samples in different states. The spheroidization of the α_s , as well as their shortening, is one of the main reasons for increasing the elongation in compo casting samples in semi-solid state compared to casting samples in squeeze casting and sand casting. Also, according to the results of porosity percentage for squeeze casting and sand casting, and higher porosity compared to that in compo casting samples in the semi-solid state, this increase in the percentage of porosity leads to concentration of greater stress around the cavities and the samples break sooner. Another reason is the presence of larger intermetallic particles and concentration of higher stress around them, which make the samples break faster.

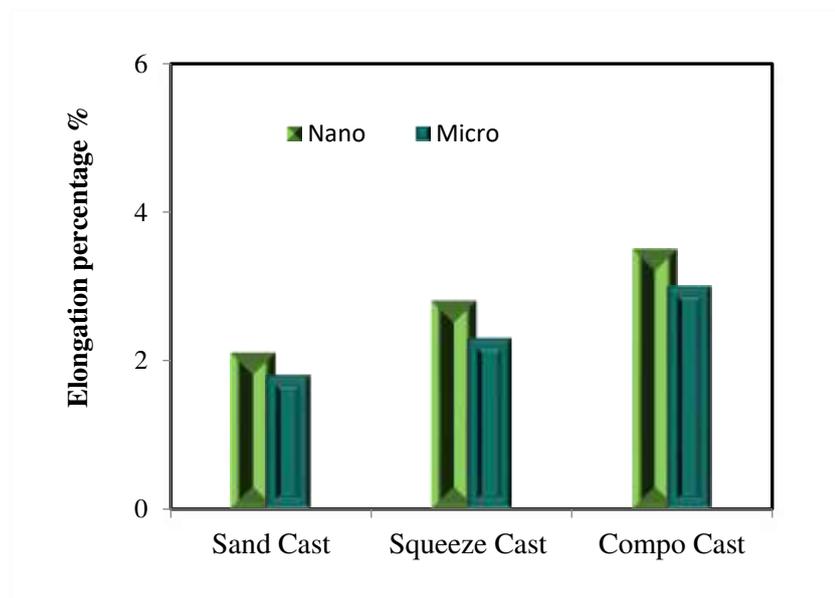


Fig 5. Elongation percentage chart in different casting conditions.

Conclusion

Tensile strength in comp casting sample in semi-solid state is higher than sand casting and squeeze casting due to the proper distribution of reinforcing particles and the absence of large intermetallic particles. Also, in all samples, the tensile strength of the heat treatment samples has increased by about 30%. The reason for the difference in the yield stress between the reinforced and non-reinforced particles is alumina nano particles. At the time of tension, these particles prevent the movement of dislocations and increase the work hardening. Also, the difference in the yield stress in the reinforced and non-reinforced samples in compo casting samples in semi-solid state is greater than that in other samples. The reason for this greater difference is the better distribution of nano particles in compo casting samples in semi solid state, and greater agglomeration of the reinforcing particles in the squeeze casting and sand casting.

Conflict of Interest/Competing Interests

The author has no conflicts of interest/competing interests to declare that are relevant to the content of this article.

- The contents of this manuscript are not now under consideration for publication elsewhere;
- The contents of this manuscript have not been copyrighted or published previously.
- The contents of this manuscript will not be copyrighted, submitted, or published elsewhere, while acceptance by the Journal is under consideration.

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Ethics declarations

We confirm that any aspect of the work covered in this manuscript that has involved human patients has been conducted with the ethical approval of all relevant bodies and that such approvals are acknowledged within the manuscript. Written consent to publish potentially identifying information, such as details or the case and photographs, was obtained from the patient(s) or their legal guardian(s).

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Informed Consent

Informed consent was obtained from all individual participants included in the study.

Consent to Participate

All the authors listed in the manuscript are agree to participate in this research study.

Consent for Publication

We confirm that the manuscript has been read and approved by all named authors. We confirm that the order of authors listed in the manuscript has been approved by all named authors.

Conflict of Interest

We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

Human and Animal Rights

This article does not contain any studies involving animals or human participants performed by any of the authors.

Financial Interests

No financial interests.

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