Research Article

Effect of Reinforcements on Mechanical Properties of Nickel Alloy Hybrid Metal Matrix Composites Processed by Sand Mold Technique

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Abstract
Hybrid Metal Matrix Composites (HMMCs) have gained wide applications in aerospace, marine, and domestic areas because of its significant properties relative to external forces and enabling environment. In present research work, Ni-alloy selected as a matrix and Al_2O_3 of 40–80 µm and TiO_2 of 1–5 µm were selected as reinforcements. The composites were prepared by keeping 9 wt. % of TiO_2 as unvarying and Al_2O_3 is varied from 3 weight % to 12 weight % in steps of 3 weight %. Induction furnace is used for the casting of composites and mixing is done by using mechanical stirring at 160 rpm for a time period of 5 min. The prepared composites are then tested for their tensile and hardness as per the ASTM standards. The Scanning Electron Microscopy was used for microstructural study. From experimentation, it was observed that increment in the weight percentage of Al_2O_3 with constant TiO_2 increases the mechanical properties of hybrid composites and proper stirring improves homogeneity in the composite material. The test results show that the addition of Al_2O_3 up to 9 weight percent increases in tensile strength compared to Ni alloy and tensile strength slowly decreases with the addition of Al_2O_3 and that the hardness values are directly proportional to the weight percent of the addition of Al_2O_3 / TiO_2.

Keywords: Nickel alloy, Sand mold casting, Al_2O_3, TiO_2, HMMCs, Mechanical properties

1 Introduction

Our ever-growing technology drives our industrial growth in a wide range of fields, including automotive, electronics, aerospace and marine. Metals, polymers, ceramics like conventional alloy barely satisfy the stringent requirements of the fast-paced industrial development [1]. Every material has its own microstructure, modification of structure using different techniques we might be able to achieve desired mechanical properties which can satisfy our industrial need. Affinity towards the complex

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materials has increased to achieve better performances in our engineering practices [2]. An advance in the technology requires development in the materials with optimized weight and cost, rigorousness, performance and material quality matching military standards [3]. The improved physical and mechanical properties of the composites like high modulus and strength, better ductility and weight to strength proportion, excellent thermal expansion coefficient with wear and corrosion resistance. Ni-alloy is known for its superior tribological and mechanical properties at elevated temperatures which makes it a desirable component in a turbine engine, marine and aerospace products. Composites having Ni-alloy as a matrix may lead greater mechanical properties at higher temperatures. The Ni-alloy based composites also have leaver density and may find application in many industrial sectors [4]–[6]. Lower cost and reliable manufacturing methods may lead the Ni-alloy composite to find more applications to produce wide verity of aerospace and industrial components [7]. These reasons have provided the much-required motivation for the material engineers and scientists to carry on experiments systematically with flower object lenses to develop metal-based composites. Repeated attempts are made especially with alloy design of surface areas to fulfill this need for high-performance functional materials. In particular, particulate enhanced metal matrix composites, MMCs, shows in the neighborhood of Isotropic properties corresponding to a continuously enhanced matriximate, many successful techniques have been developed to produce hybrid composites. Standard metallurgical technology may be used for non-composite manufacturing and traditional processes for these materials [8]–[15]. Nickel alloy provides a great resistance to specific chemicals and some are greatly versatile and capable of handling complex processes and waste streams. It is a fact that versatile alloys are much fewer than stainless steels to pitting by stress cracking and the attack of cracks in hot chloride acid. Nickel-based austenitic alloys appear to be a promising substitution to austenitic stainless steels owing to their greater corrosive resistance, thermal and mechanical properties. Ni-alloy based hybrid composites are used in pumps, valves, marine, and automobiles application [16]–[22]. Here the reinforcement in metals oxide form can be used. Development of metal matrix composites (MMCs) has been gaining more number of projects throughout the world. The methods used in the manufacture of metal matrix compounds are metal injection moldings, friction stirring process (FSP), liquid manufacturing method, solid-state manufacturing method, etc. Other techniques to develop metal matrix composites are chemical vapor deposition, electroplating, agitation, power metallurgy, gas infiltration, spring formation etc [23], [24]. In this present research, reinforcement like Al_2O_3 and TiO_2 are mixed with nickel alloy using the conventional stir casting method.

2 Methods and Materials

The hybrid metal matrix Ni-alloy composites; varying from 3 to 12 wt. % Al_2O_3 and constant 9 wt. % TiO_2 was formed with the help of the stirring casting method. The equipped hybrid MMC composites were machined using CNC toward perform the different test. The hybrid composite material is examine for the microstructure to recognize the uniform distribution of reinforcing particle in the nickel alloy. Mechanical properties such as hardness, tensile testing are measured. Scanning electron microscope (SEM), Energy dispersion spectrometer (EDS) tests are performed to recognize the relationship between matrix and reinforcements [25]–[27]. The test consequences are comparing through the Ni-alloy to verify the testing. The elemental composition of Ni-alloy is shown in Table 1. The size of the TiO_2 particles is 1–5 µm and the Al_2O_3 particles of size 40–80 µm they were used as reinforcement. The TiO_2 of 9 wt. % composites remained the same throughout the experiment, while Al_2O_3 varies from 3 weight % to 12 weight % in a step of 3 weight percent.

Table 1: Elemental composition of ASTM A 494 M35-1 Nickel alloy

Elements	Percentage
Nickel	63 Min
Copper	33 Max
Iron	3.5 Max
Manganese	1.5 Max
Silicon	1.25 Max
Columbium (Niobium)	0.5 Max
Carbon	0.35 Max
Phosphorus	0.03 Max
Sulfur	0.02 Max

2.1 *Matrix material*

Nickel in basic structure or alloyed with various metals and materials has made important contributions to our current society and is committed to continuing to provide materials for a much more challenging future. Nickel is an adaptable element, and most metals can be alloyed. Nickel and nickel amalgam are used for a broad variety of uses due to their ability to withstand a wide range of intense working conditions including harmful circumstances like high temperatures, high loads, consistency, metallurgical solidity, manufacturing and weldability. Most of uses require high consumption and potentially heat obstruction for airplane gas turbines, car fumes valves, atomic force frameworks and petrochemical applications.

2.2 *Alumina (Al_2O_3)*

Aluminum oxide (Al_2O_3), an inorganic material called alumina, would able to come back to the steadier alpha hexa stage at raised temperatures for some crystalline stages. Alumina is the most financially savvy and generally utilized product in the building earthenware production family. This is strong, consumption safe and has remarkable protection properties, and at high temperatures, high quality and hardness is impervious to solid acids and soluble bases. Aluminium oxide (Al_2O_3) SEM analysis, as shown in Figure 1(a).

2.3 *Titanium dioxide (TiO_2)*

Titanium, the ninth most regular component in the covering of the earth, is a mineral found normally in plants and creatures. Titanium responds normally with oxygen to frame titanium oxides, ordinarily found in crude materials, unique residue, sand, and soil. Unadulterated titanium dioxide is a fine white powder which gives splendid white shading. SEM analysis of titanium dioxide (TiO_2), as shown in Figure 1(b).

2.4 *Casting*

The base metals along with reinforcements metal are melted using induction furnace it's heated up to melting temperature of 1560°C and reinforcements were preheated at 600°C to eliminate surface impurity and to improve the wettability of the reinforcements. Motorizes

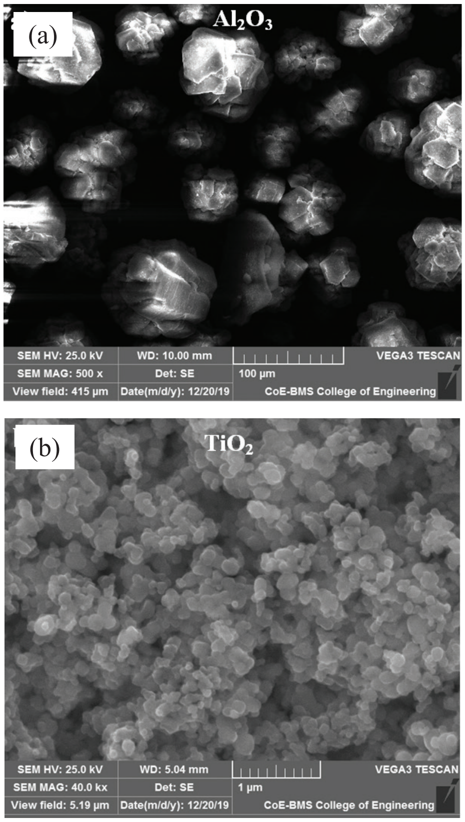

Figure 1: SEM analysis of (a) Al_2O_3 and (b) TiO_2 reinforcements particles of hybrid composites.

stirrer is used to obtain homogeneous mixing of composites of hybrid metal matrix with addition of reinforcements from weight percent 3 to 12 in increment of 3%. Degassing tablets were added to matrix material in order to remove the entrapped air from melt. When the matrix in the induction furnace reaches 1560°C, the preheated reinforcement is added with different wt. % to the vortex of a nickel alloy. The stirring is then done using graphite-coated stirrer for duration of 5 min at a speed of 160 rpm to ensure the uniform distribution of the reinforcements. The prepared melt was then poured into the mold and permitted to solidify at room temperature. The solidified cast is then machined to prepare the required tensile and hardness specimens as per ASTM standards.

3 Testing of Hybrid Composites

Composites materials are prepared and machined to produce the specimens used to study the microstructure, tensile strength, and hardness.

3.1 *Microstructure*

The example gathered from the casting was grounded to separate burrs and cleaned to accomplish a harsh surface completion in the blasters, which was additionally cleaned utilizing 400, 600, 800 and 1000 coarseness sanding sheets. Following this strategy, clean tenderly utilizing a weakened Al_2O_3 plate polisher to expel all the knocks and scratches on a superficial level for a mirror-like surface completion. Until testing with NIKON-ECLIPSE LV 150 Japan Metallurgical Optical Microscope, a Kroll reagent (92 mL refined water, 6 mL corrosive nitric and 2 mL corrosive hydrofluoric) with a 10–20 s cylinder was bored in consistency with ASTM E3-11 gauges. An infinitesimal examination to decide the homogeneous dissemination of the fortifying particles in the composite framework was then performed.

3.2 *Hardness*

ASTM E92 hardness test was performed using Vickers MITUTOYO 201-101E hardness test on samples. The test apparatus has a pyramid-shaped diamond indicator with a square base and the sample surface is indented. The sample was then put on the test table, and for 15 s a load of 10 kg was applied to the sample surface. The charge was then released, and on a microscopic spiral scale, the indentation on the sample was seen. This cycle was repeated on the surface of each sample at 5 different locations. Vickers hardness sum was then calculated, and the mean value was taken as the value of the sample hardness.

3.3 *Tensile*

Tensile stress testing of samples was carried out with automated general testing machine Tinius Olsen. Samples are shaped in conjunction with ASTM E8M-16 a, and then fixed between the general test machine (UTM) joints. The input data for the sample is then loaded into the UTM system. The tensile charge was then slowly added to both ends of the sample by withdrawing the process at 0.5 mm/min.

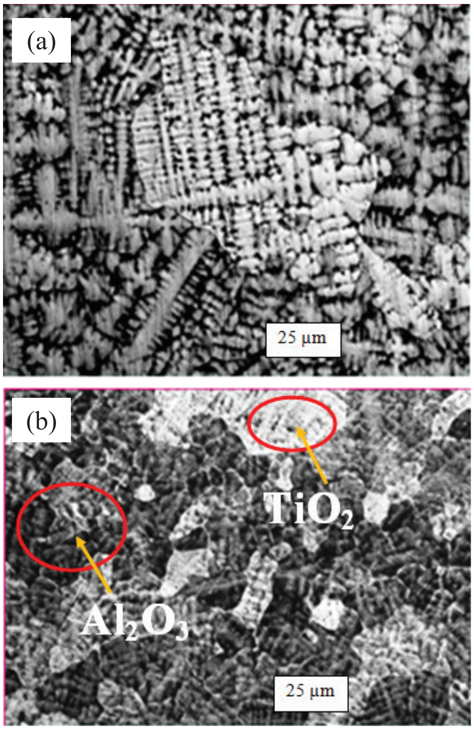

Figure 2: Microstructure images for (a) Unreinforced Ni-alloy matrix and (b) 9 weight % of Ni-alloy/Al_2O_3/TiO_2 hybrid metal matrix composites.

4 Results and Discussion

The following sections explain assessment of varied composite structure for their mechanical properties, and microstructural behaviour.

4.1 *Analysis of microstructure*

It is inferred from the micrographs in Figure 2 that the apparent dark grey area is Al_2O_3, and the solid TiO_2 solution for the reinforcement particles is the white area, while the remaining area is the Ni-alloy matrix. The white and dark spots evident in the microstructure picture illustrate the accumulation of TiO_2 and Al_2O_3 particles. Heterogeneous solid solutions are formed to promote the development of a fine dendrite structure in the metal matrix, resulting in better bonding and polished grain pattern. This is due to the 10 min stirring cycle preheating temperature of reinforcements and wetting agent during the casting process, which distributes the metal matrix reinforcement particles

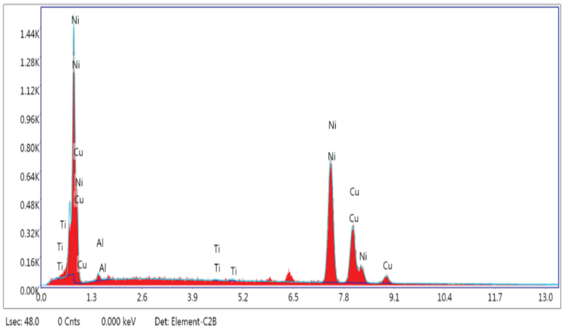

Figure 3: EDX spectrum of hybrid composites of nickel alloy hybrid composites.

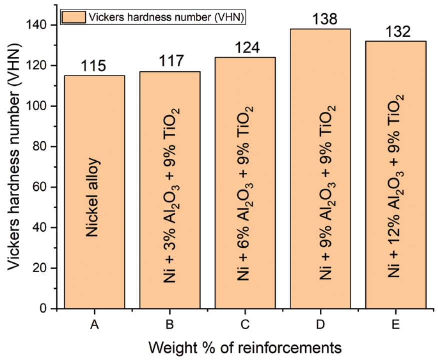

Figure 4: Hardness of Ni-alloy and hybrid composites series.

evenly with minimum mass. The arms of dendrite is long enough in Ni-alloy but it is restricted in hybrid composites structure, this is due to inhibition of reinforcements in alloy will restrict the growth of the dendrite arm during solidification process. This short growth of dendrite results substantiel improvement in mechanical properties. Particle additions studies show that mechanical properties strengthen due to the heterogeneous nucleation of the grains of reinforcements with the creation of an accurate structure.

EDAX spectrum (Figure 3) for the identification of elements in hybrid composites of Ni-alloy metal matrix. The Al_2O_3 and TiO_2, which are the high-intensity Ni-alloy in the EDAX, can be found in the synthesis of the Al and Ti elements. It has been confirmed that all planned elements are incorporated into potential composites in the analysis.

4.2 *Micro hardness*

The improvement in the micro-hardness of the composites is primarily due to the following reasons. Particles are added as reinforcements penetrate a soft elongated metal matrix refined structure and interrupt the movement of atoms as dislocation occurs, thus providing more resistance to plastic deformation. This due to ductile to brittle transient. The resistance of the grain boundaries increases as the intensity of the dislocation of the atoms decreases with an increase in the weight ratio of the reinforcements that give strength to the matrix and, therefore, an increase in the hardness is observed of the composites.

The hardness values show that the tendency increases (Figure 4) as the percentage addition of Al_2O_3/TiO_2 are increased to 3 wt. % to 9 wt. %. Thus, the resistance capacity of the matrix is increased with the addition of Al_2O_3 /TiO_2 particles and further reduced due to decreases in the fluidity of molten metal. The obtained result shows that the composites have greater hardness values when compared with the Ni-alloy and the Ni + 9% TiO_2 + 9 % Al_2O_3 composite shows higher hardness among all composite series.

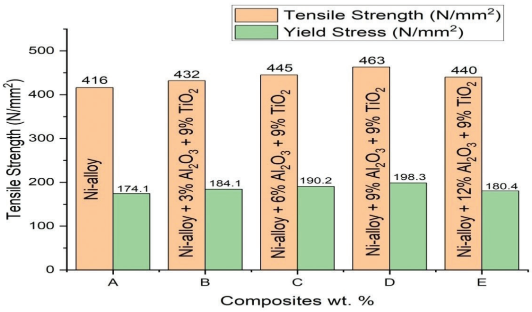

Figure 5: Tensile strength results of nickel alloy hybrid metal matrix composites.

4.3 *Tensile strength*

From Figure 5, it is clearly seen that the tensile strength of hybrid composites has improved significantly compared to unreinforced nickel alloy. Increased tensile strength can be associated with the fact that solid TiO_2/Al_2O_3 reinforcing materials with better mechanical properties are incorporated into the base alloy. It performs the double action of transferring and resisting the applied tensile load. The particles impede

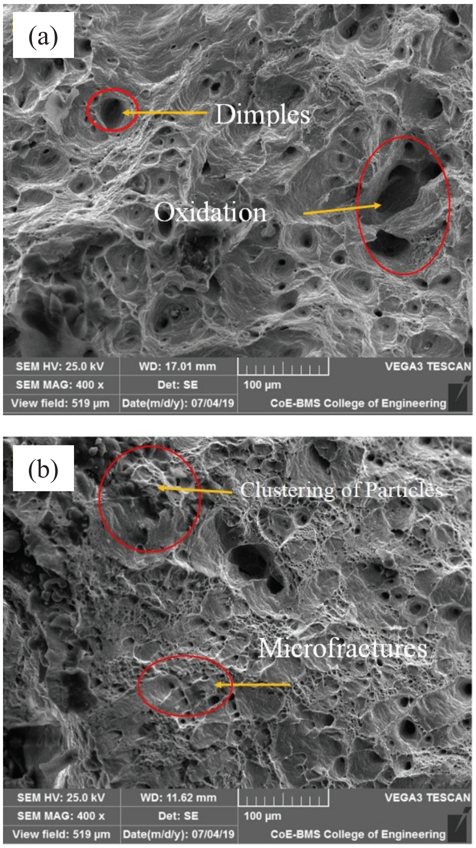

Figure 6: SEM micrographs of the tensile strength fractured surfaces for (a) Unreinforced Ni-alloy matrix and (b) 9 weight % of Ni-alloy/Al_2O_3/TiO_2 hybrid metal matrix composites.

dislocation movement and strengthen the unreinforced alloy material by forming a better bond with the atoms in the adjacent metal matrix and improving the tensile strength of hybrid composites. As the tensile load increases, microvides forms subsequently expand and combine to form larger voids resulting in cracking. At this point, the sample is subject to a fracture.

The improvement in tensile strength can be explained by the Orowan reinforcement mechanism, where dispersed reinforcement particles will acts as a obstacles far the crack propagation in the composites. Also presence of reinforcement particles generates disturbances, which increases the intensity of dislocation. The tensile strength is enhanced with the addition of Al_2O_3/TiO_2 particles up to wt. % of 9 and beyond which at wt. % of 12 the tendency reverses due to the formation of agglomeration the bonding between the matrix and reinforced particles in the location is weak. Thus 9 wt. % of Al_2O_3/ TiO_2 particles is considered as optimum.

Figure 6 shows the SEM micrographs of fractured surfaces of Ni-alloy matrix reinforced with TiO_2 and Al_2O_3, which reveals that the formation of more dimples on the fractured surface. Dimples are the results of the formation and coalescence of micro-voids. The particles perform as barrier in the direction of the propagation of micro fractures produced in the matrix through the plastic deformation. From the fractured seen images it is evident that with the addition of hard ceramic particles, the composite have become brittle. The transgranular fracture was observed in the matrix and intergranular behaviors was observed when crack reaches the obstacle particles, thus the time taken for the propagation of crack increases with the increase in particles weight percentage which results higher resistance to the applied tensile load.

5 Conclusions

Ni-alloy and Al_2O_3/ TiO_2 reinforced composites were effectively direct by stir casting direction using a changeable reinforcement particles from 3 wt. % to 12 wt. % with an increment of 3 wt. %. From the analysis of the cast specimen, the following conclusions are drawn.

Composite hybrid with nickel-based alloys can be successfully cast from a conventional stir casting route. The uniform distribution of Al_2O_3/ TiO_2 particles are achieved with proper stirring time and speed. The density variation of both matrix and reinforcements permits the uniform distribution. Microstructure analysis using SEM shows the uniform distribution of Al_2O_3/ TiO_2 particulates with the smallest amount of porosities and agglomeration. The Tensile strength is enhanced with the addition of Al_2O_3/ TiO_2 particles up to 9 wt. %, and the tendency reverses due to the formation of agglomeration the bonding between the matrix and reinforced particles in the location is weak and also due to an increase in the strain hardening effect. The obtained result shows that the composites have greater hardness values when compared with the matrix alloy and the Ni + 9% TiO_2 + 9 % Al_2O_3 composite exhibits high hardness compared to other composites series.

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