Tribological and Corrosion analysis of Co-20Al-GNSA composites produced through powder metallurgy process

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Abstract. In this study, Co-20Al-GNSA metal matrix composites were produced using mechanical alloying process. The Co-20Al-GNSA composites were mixed using a high-energy ball mill at a constant speed of 350 rpm for 2 hours. The composite powders were then characterized for their morphological study using Scanning Electron Microscope. The composite powders are then compressed and sintered at 500MPa and 700°C respectively. The density and compressive strength of the composite materials shows decrement values whereas the wear resistance of the composite materials has increased considerably. The mechanism of wear was identified as abrasive wear. The electrochemical corrosion test also reveals that the Co-20Al-10GNSA composites have better corrosion resistance. The weight-loss corrosion test also shows that the composites with 10GNSA content have better corrosion resistance.

Keywords: Wear, Corrosion, Powder Metallurgy, Microhardness.

1. Introduction
The exploitation of hybrid composites for the potential replacement of conventional metals has been drastically increased in several applications such as automobile industries, commercial industrial applications, and also in aerospace industries where enhanced mechanical, wear and corrosion resistance properties are expected. Hence it was the main objective of the researchers to develop materials with lesser density with better tribological and corrosion performance[1–3].

In the process of developing a composite material, it is very important to select the matrix materials and reinforcements with the good wet ability to improve the bonding of the composite materials. Another important factor is the selection of the fabrication method and its working parameters as per the matrix and reinforcement materials. Now a day the production economy is one of the important factors due to the economic thoughtfulness of the industries[4–7]. They prefer low-cost composites, to reduce the production cost due to the raw materials. The Co is a material with very good mechanical and corrosion resistance property whereas it is very costly. So it is necessary to tailor...
the mechanical properties using low-cost reinforcements such as Al and GNSA. The most generally used reinforcements are SiC, Al₂O₃, and TiO₂. The ceramic particles Al₂O₃ and TiO₂ don’t have good wetting characteristics[8–10]. Thereby to improve the wettability the Ground Nut Shell Ash (GNSA) is utilized as secondary reinforcement.

The uniform dispersion of reinforcement was another area that has to be addressed while selecting a fabrication process. There are many methods such as stir casting to produce composite materials whereas achieving uniform dispersion is not possible due to cluster formation. But it is possible to produce composite materials with a uniform dispersion of reinforcements using the powder metallurgy process. Another reason for choosing powder metallurgy was their cost-effectiveness and their reliability for the production of high melting point materials[5,8,11,12].

In this study, a range of combinations of Co-20Al-GNSA hybrid composites was formed via the powder metallurgy process. The hybrid composites were then made up into 10mm cylindrical pellets using a die setup made up of high-speed steel die. The muffle furnace was utilized to harden the compacted green pellets using a sintering operation. The microhardness, density, and compressive strength of the composite materials were studied and reported. The pin on disc apparatus and electrochemical workstation were utilized to study the wear and corrosion resistance properties respectively. Thus the main purpose of this effort is to develop hybrid composite materials with better mechanical, improved wear, and corrosion resistance properties that can be employed in automobile, industrial, and aerospace applications.

2. Materials and Methods
The chemicals used in this work are of research-grade (99.5% purity). The composite powders are synthesized using a high-energy ball mill that comprises tungsten carbide balls. The ball milling process was carried out for a duration of 2 hours at a speed of 350 rpm in the existence of toluene as a process control agent to acquire homogenous hybrid composites. The homogenously unified composite powders are then packed down using a uniaxial hydraulic press at 500 Mpa and sintered at 700°C to produce a 10 mm cylindrical pellet. The composite materials are characterized using SEM to find out the morphology of the composite materials. The microhardness of the Co-20Al-GNSA hybrid composites was carried out at 0.5 kg load using Vickers hardness equipment and standard deviation values are considered and reported. The density of the Co-20Al-GNSA hybrid composites was calculated based on the Archimedes principle. The 10 mm diameter composite pellets are compressed using the universal testing machine (UTM) at a uniform and gradual speed rate of 3 mm min⁻¹[8,13,14]. The wear analysis was carried out at constant load, constant speed, and sliding distance of 10N, 1.5 m/s, and 1000m respectively. The electrochemical corrosion analysis was carried out using a bio-logic electrochemical workstation. The workstain consists of three electrodes, the platinum counter electrode, Al/AgCl reference electrode and composite pellets as working electrode. The scan was carried out at 5mV/s. The composite pellets are immersed in 3% NaCl solution for 1 hour so as to stabilize the open circuit potential. The weight-loss corrosion analysis was carried out with various corrosive media such as 0.1N HCl, 0.1N H₂SO₄ and 3% NaCl solution. The composite pellets are immersed in the corrosive media for 24 hours. The composite specimens are weighed before and after the test and the weight loss is calculated.[13,15].

3. Results and Discussion
3.1 Density and Microhardness.
The SEM image of the Co-20Al-5GNSA hybrid composites is shown in Figure.1. The SEM image is taken in secondary electron mode. It is observed that there is uniform dispersion of Co, Al, and GNSA particles in hybrid composite material. Figure.2 exhibits the microhardness and density graphs of Co-20Al-GNSA. The density of the Co-20Al-GNSA hybrid composites increases slightly with the addition of GNSA particles. The density of Co-20Al-2.5GNSA composite was 5.2 g/cm³ which increase
slightly to 5 g/cm$^3$ for Co-20Al-5GNSA hybrid composites. The further addition of GNSA reinforcements resulted in a decrease in the density of the Co-20Al-10GNSA hybrid composites (5 g/cm$^3$). The microhardness of the Co-20Al-GNSA hybrid composite increases linearly up to 5% GNSA reinforcement further addition of GNSA particles has resulted in a slight reduction in the microhardness of the composite material.

Figure 1. SEM image of Co-20Al-5GNSA hybrid composite

Figure 2. Microhardness and Density of Co-20Al-GNSA hybrid composites
3.2 Compressive Strength
The Compressive strength of Co-20Al-5GNSA hybrid composites is 112 MPa which is better compared to Co-20Al-2.5GNSA (110 MPa) and Co-20Al-10GNSA (108 MPa) hybrid composites. The compressive strength increased gradually with GNSA addition till it reaches 5% GNSA, whereas further addition of GNSA does not influence the compressive strength of the hybrid composites. Figure.3 represents the compressive strength of the Co-20Al-GNSA hybrid composites.

![Compressive Strength Graph](image)

Figure.3 Compressive Strength of Co-20Al-GNSA hybrid composites

3.3 Wear and COF Analysis
The wear analysis results of Co-20Al-GNSA hybrid composites are represented in Figure.4. The wear test was carried out at a constant load of 10N, constant sliding speed of 1.5 m/s, and constant sliding distance of 1000m. The wear loss of the Co-20Al-10GNSA hybrid composites exhibited better wear resistance and COF values compared to that of other specimens. The Co-20Al-2.5GNSA has produced a COF value of 0.9 whereas the COF value of Co-20Al-10GNSA is 0.6. Hence it can be confirmed that the addition of GNSA particles has a good influence in increasing the wear resistance of the hybrid composite materials. Figure.5 represents the SEM image of Co-20Al-10GNSA hybrid composites after the wear test. From the pattern of wear track, it is evident that the major wear mechanism is abrasive wear.
Figure 4: Wear loss and COF of Co-20Al-GNSA hybrid composites

Figure 5: SEM image of Co-20Al-10GNSA hybrid composite after wear test
3.4 Corrosion Analysis

Figure 6 shows the weight-loss corrosion graphs of Co-20Al-GNSA hybrid composites at various corrosive media such as 3% NaCl, 0.1N HCl, and 0.1N H$_2$SO$_4$. From the graph, it can be concluded that the weight loss of the composites decreases with the increase in GNSA content. The weight loss of the Co-20Al-10GNSA hybrid composite is better compared to other combinations in all kinds of corrosive media. The weight loss was maximum for 0.1 N H$_2$SO$_4$ for all samples compared to other corrosive media. The weight loss was minimum in 3% NaCl solution. The electrochemical corrosion analysis was carried out using three-electrode systems using the composite pellets as the working electrode. The potentiodynamic polarization results shows that the Co-20Al-10GNSA hybrid composites have exhibited better $E_{corr}$ (-0.442 V) and $i_{corr}$ values (1.5 mA/cm$^2$) compared to that of Co-20Al-5GNSA (-0.448V & 1.7 mA/cm$^2$) and Co-20Al-2.5 GNSA (-0.453V & 1.9 mA/cm$^2$). It is evident that the $E_{corr}$ values are shifted to more positive side and the $i_{corr}$ values decreases with the increase in GNSA content which confirms the increase in corrosion resistance.

![Figure 6 Weight loss corrosion results of Co-20Al-GNSA hybrid composites](image-url)
4. Conclusions
The Co-20Al-GNSA hybrid composites were amalgamated by employing a high-energy ball mill.

- The Microhardness and density of the Co-20Al-5GNSA hybrid composites have improved compared to other samples.
- The compressive strength of the Co-20Al-5GNSA hybrid composite was 112 MPa and superior compared to other combinations.
- The wear analysis authenticates that Co-20Al-10GNSA hybrid composites exhibited better wear resistance and coefficient of friction.
- The potentiometric polarization analysis shows that the Co-20Al-10GNSA hybrid composites have enhanced corrosion resistance due to the existence of GNSA particles.
- The weight-loss corrosion analysis also proves that the Co-20Al-10GNSA hybrid composites have better corrosion resistance.

From the conclusion of this study, it can be accomplished that the Co-20Al-10GNSA hybrid composites have experienced a slight decrease in density, microhardness, and compressive strength but exhibits better wear and corrosion resistance. Hence it can be concluded that Co-20Al-10GNSA hybrid composites have better tribological and corrosion resistance with decent mechanical properties which may be considered for potential industrial applications.

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