Section A -Research paper
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The Mechanical Characteristics of Al6061/Nickel and Al6061/Chromium Metal Matrix Composites: A Comparative Analysis

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Abstract
In this work, we focus on contrasting the mechanical properties of two metal matrix composites made from Al6061/Ni and Al6061/Cr. Metal matrix composites based on Al6061, reinforced with proportions from 0% to 2.7% in 0.9 percent increments, created by the stir casting method. In order to enhance the self-lubricating behavior and wettability, a fixed fraction of 2.7 wt. % of graphite and 0.9 wt. % of magnesium was added. The developed MMCs were subjected to mechanical testing as per ASTM standards. Compared to chromium, nickel's contribution to the strengthening action is crucial. In terms of ultimate tensile strength and hardness, Al6061/Ni MMCs outperform Al6061/Cr MMCs, but Al6061/Cr MMCs excel in elongation, flexural strength, and impact strength. This study's findings confirmed that adding nickel and chromium to Al6061 alloy induced structural modifications that improved the material's mechanical properties.
Keywords: Al6061, Nickel, Chromium, Composites, Stir Casting, Mechanical characteristics

1. Introduction

Due to rapid advances in science and technology, the demand for high-tech materials in the engineering sector has skyrocketed in recent decades. Aluminum is widely used in the automotive, building, packaging, transportation, and, of course, design industries. Because of its low density, high strength-to-weight ratio, outstanding formability, and improved corrosion resistance in comparison to other alloys, Al6061 is in great demand. There is currently a great deal of effort being put into discovering ways to improve the strength and corrosion resistance of metal matrix composites. According to research conducted by Bojinov et al. (2002), nickel is the superior material for certain devices and components due to its strength at high temperatures and its resistance to corrosion. When Wong et al. (2006) added reinforced particles of nickel to an aluminum-based metal matrix composite, they found that the composite's hardness, yield strength, and ultimate tensile strength increased, while its ductility reduced. Sagar and Radhakrishna (2017) created a nickel-reinforced aluminium matrix composite using stir casting. Al6061 MMC reinforced with 0.4% nickel has improved hardness, tensile strength, and toughness compared to 2.3% nickel. Intermetallic increases with increasing nickel particle reinforcement (higher than 0.4%), reducing composite strength.

Pazman et al. (2010) studied the formation of intermetallic phases between Ni and Al-SiC

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composites and composite fabricated by powder metallurgy route at the sintering temperature of 580ºC which improve the corrosion resistant property due to favorable condition the diffusion of Ni into the matrix. Kumar et al. (2011) observed the influence of hard ceramics reinforcement into matrix metal for aluminum metal matrix composites. It is identified that if the reinforcement is increased, the hardness of the composite is also enhanced significantly. It is evident that the structure and properties of reinforcement regulate the mechanical characteristics of the metal matrix composites. Ahmad (2018) casted an Al LM6-based composite reinforced with different weight % (0.05, 0.1 and 0.15) of chromium and investigated the mechanical behavior of composites. Experimental Results revealed that superior mechanical properties like hardness and toughness of composite observed by the addition of chromium but limited up to 0.35 wt.%. As a result, inexpensive transition metals like Ni and Cr are receiving greater research for their potential to enhance mechanical qualities. Mechanical properties of Al6061 produced using the stir casting method were studied, and the impacts of Ni and Cr addition were examined.

2. Materials and Methods

The Al6061 aluminum alloy used in this research is one of the most extensively used of the 6000 series of Aluminum Alloys. It's an extruded composite with heat-treatable flexibility and moderate to high-quality capacity. Nickel and chromium are used as the reinforced particles in varying weight fractions whereas graphite and magnesium are added in fixed-weight fractions. Table 1 displays the chemical composition of the raw material, an aluminum alloy 6061.

Table 1. Chemical composition of Al 6061alloy

Element	Si	Fe	Cu	Mn	Ni	Zn	Pb	Ti	Sn	Mg	Cr	Al
Wt. %	0.43	0.7	0.24	0.14	0.05	0.25	0.24	0.15	0.001	0.80	0.25	Bal.

Table 2. Properties of micron-size reinforced particles

Al6061 Reinforced with Micron Size Particles				
Reinforcement	Nickel	Chromium	Graphite	Magnesium
Purity (%)	99.16	99.60	99.50	99.87
Particle Size (µm)	44	44	37	149
Particle Size (Mesh)	325	325	400	100
Melting Point (℃)	1450	1900	3652	650

The development of Al6061-based MMCs can be accomplished with minimal expense by using the stir-casting process. In this work, micron-size reinforced particles of Ni and Cr

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were used to fabricate Al6061-0.9 wt.% Ni, Al6061-1.8 wt.% Ni, Al6061-2.7 wt.% Ni Al6061-0.9 wt.% Cr, Al6061-1.8 wt.% Cr and Al6061-2.7 wt.% Cr MMCs at casting temperature 750˚C and stirring for 15-20 mins at 400 rpm through an automated stir casting set up. Graphite and magnesium were added in fixed weight fractions of 2.7% and 0.9% respectively to improve self-lubrication properties and wettability respectively. Specimens were prepared for tensile, flexural, hardness, and impact testing in accordance with ASTM standards once the material had fully solidified. The specimens for tensile, flexural, hardness, and impact tests were tested on a universal testing machine, Vickers hardness tester, and Charpy impact tester respectively.

3. Results and Discussions

Table 3-6 results of the mechanical behavior tests for developed MMCs – ultimate tensile stress, yield stress, percentage elongation, flexural test, impact test, hardness test. Figure 1-6 graphically represents the comparison of Al6061/Ni and Al6061/Cr MMCs.

3.1. Tensile test:

Figure 1 and 2 represent that Al6061/Ni MMCs exhibit superior tensile strength as compared to Al6061 alloy and Al6061/Cr MMCs which indicates that the addition of Ni and Cr micron size particles as reinforcement in Al6061 alloy increases the tensile strength. The maximum tensile strength has been achieved with 1.8 wt. % of Ni and Cr particles in respective MMCs. Yield stress monotonically increases with the addition of Cr particles in Al6061/Cr MMCs whereas in the case of Al6061/Ni MMCs it increases up to 1.8wt.% addition of Ni particles afterward it decreases.

Table 3. Tensile strength and elongation of developed Al6061/Ni MMCs

Sample No.	Composition Designation	Yield Stress (MPa)	Ultimate Tensile Strength (MPa)	% Elongation
Al6061	Al6061	95.24	154.32	13.4
SM1	Al6061/0.9 Ni	115.36	171.29	11.7
SM2	Al6061/1.8 Ni	133.60	184.00	10.4
SM3	Al6061/2.7Ni	127.67	168.23	9.2

Table 4. Tensile strength and elongation of developed Al6061/Cr MMCs

Sample No.	Composition Designation	Yield Stress (MPa)	Ultimate Tensile Strength (MPa)	% Elongation
Al6061	Al6061	95.24	154.32	13.4
SM4	Al6061/0.9 Cr	104.39	161.67	12.2
SM5	Al6061/1.8 Cr	118.15	172.79	11.4
SM6	Al6061/2.7 Cr	129.46	163.49	8.3

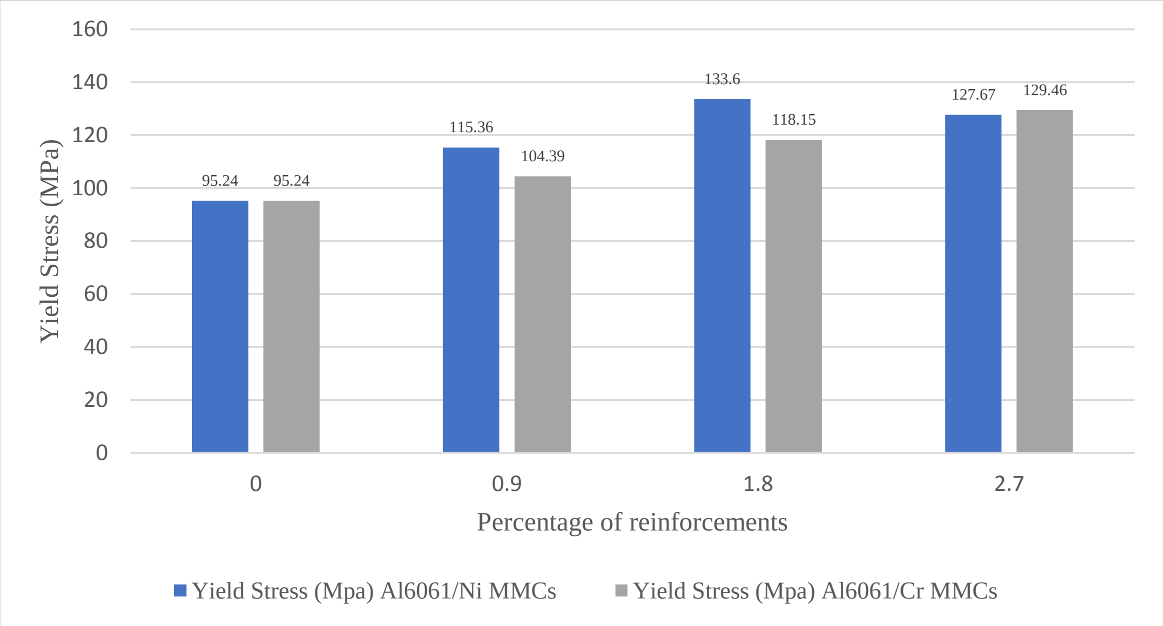

Fig.1. Influence of the Ni and Cr addition on yield stress of developed MMCs

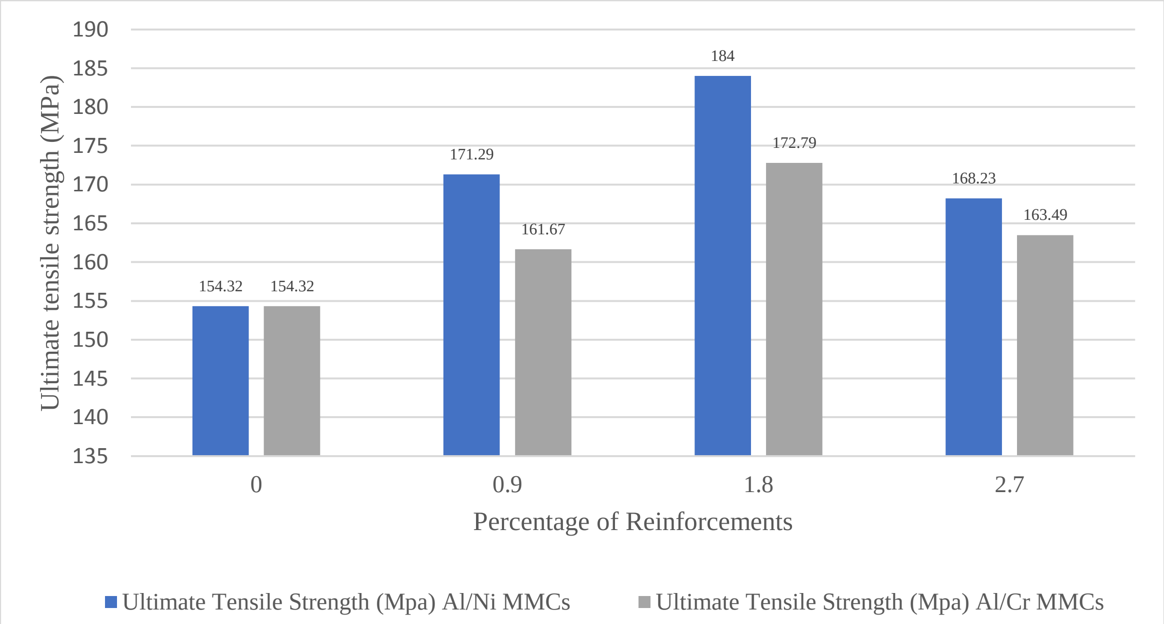

Fig.2. Influence of the Ni and Cr addition on ultimate tensile strength of developed MMCs

Results revealed that Al6061/Ni MMCs have better tensile strength as compared to Al6061/Cr MMCs. Ni has a better strengthening influence on the developed MMCs as compared to Cr. Better distribution of Ni takes place as compared to Cr, due to its smaller atomic radius. Similar results were found by Swamy et al. (2011), who developed Al6061/WC by vortex method and Babu et al. (2018) who fabricated Al6061-based MMCs reinforced with tungsten carbide and chromium micron-size particles.

3.2. Elongation

Figure 3 shows that elongation decreases monotonically with the addition of nickel particles. Subsequent equivalent addition of Cr particulates of the same size observed the same behavior but do not result in such a great variation in elongation. Initially, ductility or elongation of both types of the developed composite increased due to the addition of graphite,

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a solid lubricant. the comparative study of developed MMCs revealed that by adding chromium superior ductility of Al6061-based composites was observed as compared to Ni-reinforced Al6061 composites up to 1.8 wt.%. The reduction in elongation or ductility is due to the presence of hard reinforced particles. These results were similar to those obtained by Okafor et al. (2015) who observed that the elongation or ductility of MMCs decreases with the addition of reinforced particles.

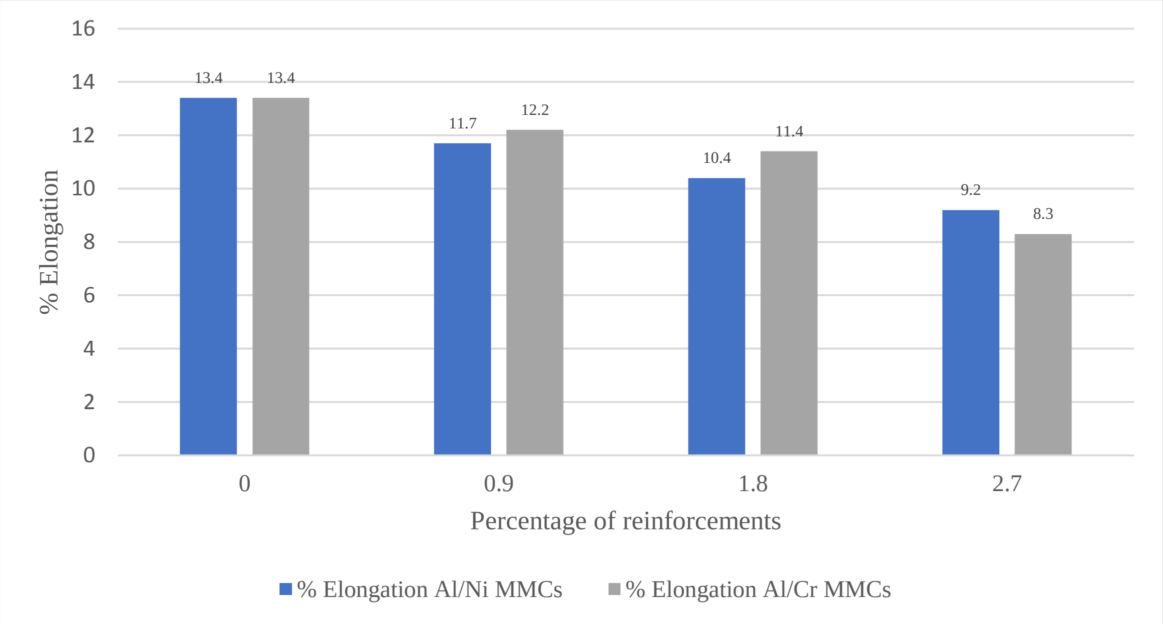

Fig.3. Influence of the Ni and Cr addition on elongation of developed MMCs

3.3. Flexural Strength:

The flexural test on the material is employed for the estimation of the bending strength of the material. Figure 4 shows the influence of nickel and chromium content on the flexural strength of cast Al6061/Ni and Al6061/Cr MMCs. Al6061/Ni MMCs and Al6061/ Cr MMCs exhibit superior flexural strength as compared to Al6061 alloy, which indicates that the addition of Ni and Cr micron size particles as reinforcement in Al6061 alloy increases the flexural strength.

Table 5. Flexural strength, microhardness, and impact strength of developed Al6061/Ni MMCs

Sample No.	Composition Designation	Flexural Strength (MPa)	Microhardness (HV)	Impact Strength (Joule)
Al6061	Al6061	299.71	70.4	10
SM1	Al6061/0.9 Ni	313.76	78.51	14
SM2	Al6061/1.8 Ni	342.55	84.46	12
SM3	Al6061/2.7Ni	316.06	86.22	11

Table 6. Flexural strength, microhardness, and impact strength of developed Al6061/Cr MMCs

ISSN 2063-5346

Sample No.	Composition Designation	Flexural Strength (MPa)	Microhardness (HV)	Impact Strength (Joule)
Al6061	Al6061	299.71	70.4	10
SM4	Al6061/0.9 Cr	327.70	76.12	17
SM5	Al6061/1.8 Cr	362.09	81.46	18
SM6	Al6061/2.7 Cr	389.67	78.20	20

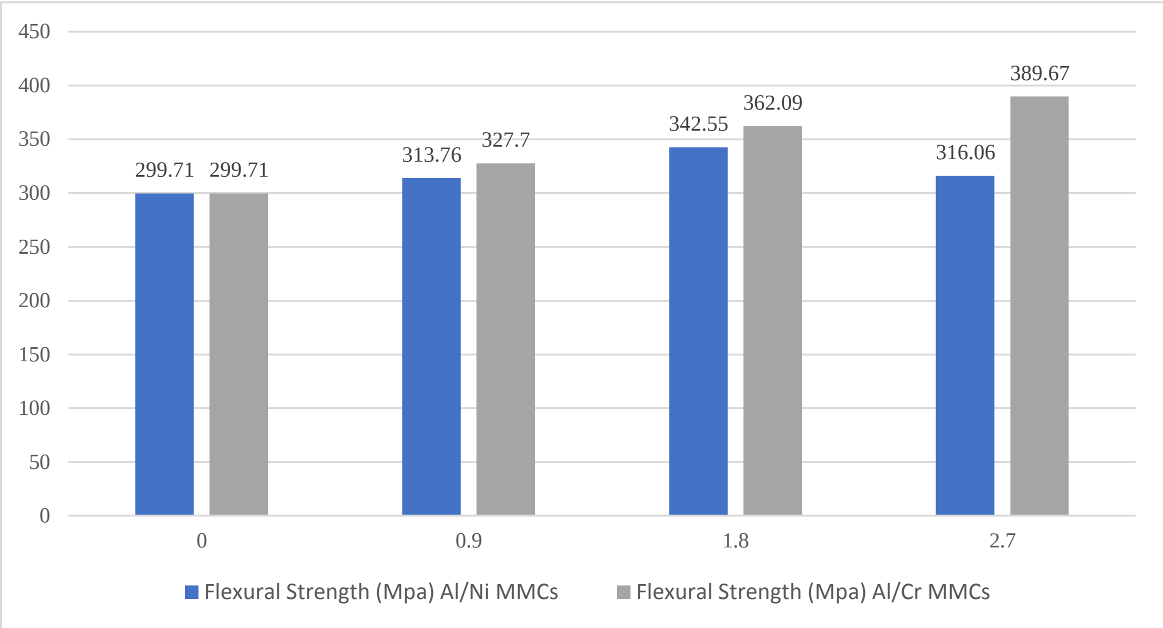

Fig.4. Influence of the Ni and Cr addition on flexural strength of developed MMCs

Figure 4 showing the influence of Ni and Cr particulate on respective MMCs. It can be seen that addition of Cr as reinforcement in Al6061 alloy effects more on flexural strength as compared to addition of Ni particles. Satheesh and Pugazhvadivu (2015) observed similar results on Al6061 based MMCs reinforced with silicon carbide and coconut shell ash particles.

3.4. Microhardness:

Any material's tribological behavior is dependent on how hard it is. Therefore, it is necessary to increase the material's hardness in order to improve tribological properties like wear resistance. Figure 5 demonstrates that when the addition of Ni micron-sized particles increased from 0 to 2.7 wt. the microhardness rose monotonically by 22.45 percent. The hardness of Al6061/Cr MMCs improves as chromium content rises in the material. Thus, the hardness of MMCs is likewise improved by the incorporation of chromium particles.

The microhardness of Al6061/1.8 Cr MMCs is the highest, coming in at a 15.7% increase over the base alloy but falling short of that of Al6061/2.7Ni MMCs. As Ni is harder than Cr, the results showed that Al6061/Ni MMCs are more durable than Al6061/Cr MMCs. Figure 5 depicts the effect of Ni and Cr reinforcements on Al6061 alloy microhardness values, with the greatest microhardness observed at 86.22 HV for Al6061/2.7Ni MMC, which is over 5.8

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percent higher than the microhardness of Al6061/1.8Cr MMC (81.46 HV). Okafor et al. (2015) found a similar pattern of hardness behavior in Ni and Cr-reinforced Al6061-4% Zinc based composites.

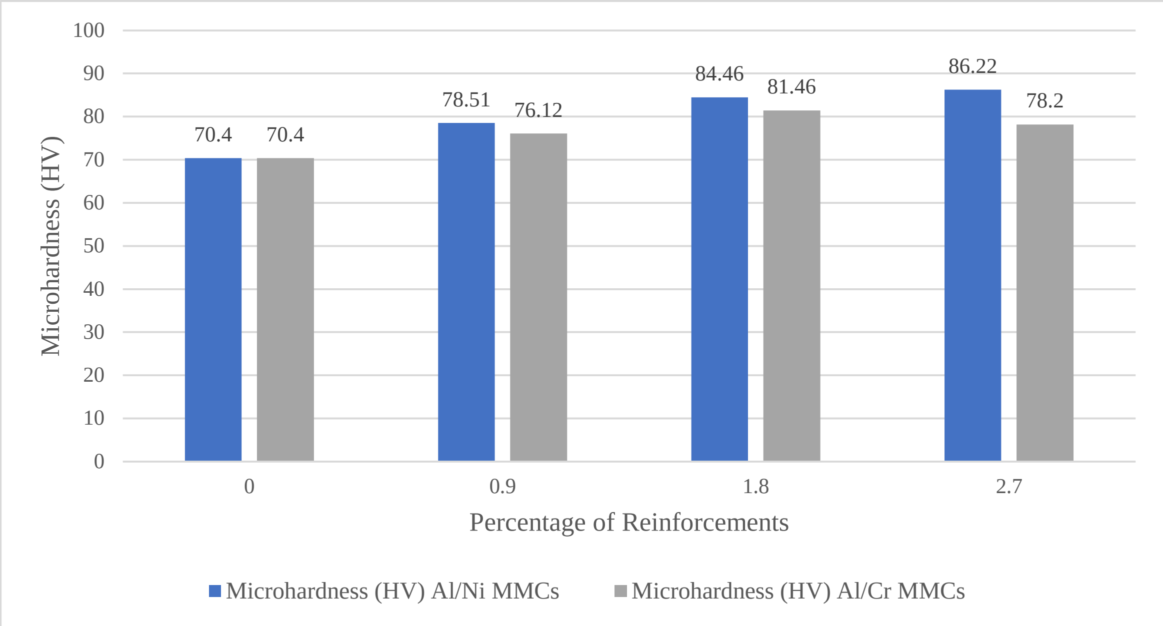

Fig.5. Influence of the Ni and Cr addition on microhardness of developed MMCs

3.5. Impact Strength

Figure 6 demonstrates that Al6061/Ni MMCs display greater impact strength than the base alloy, proving that the base alloy's impact strength is increased by the addition of Ni particles as reinforcement. The bar graph also reveals that the first increase in impact strength of Al6061/Ni MMCs from 0 wt.% to 0.9 wt.% is due to an increase in the weight percentage of Ni particles. As more Ni particles are added to MMC, the impact strength monotonically declines. In contrast, the impact strength of Al6061/Cr MMCs grows monotonically when the reinforcement weight percent of Cr particles rises.

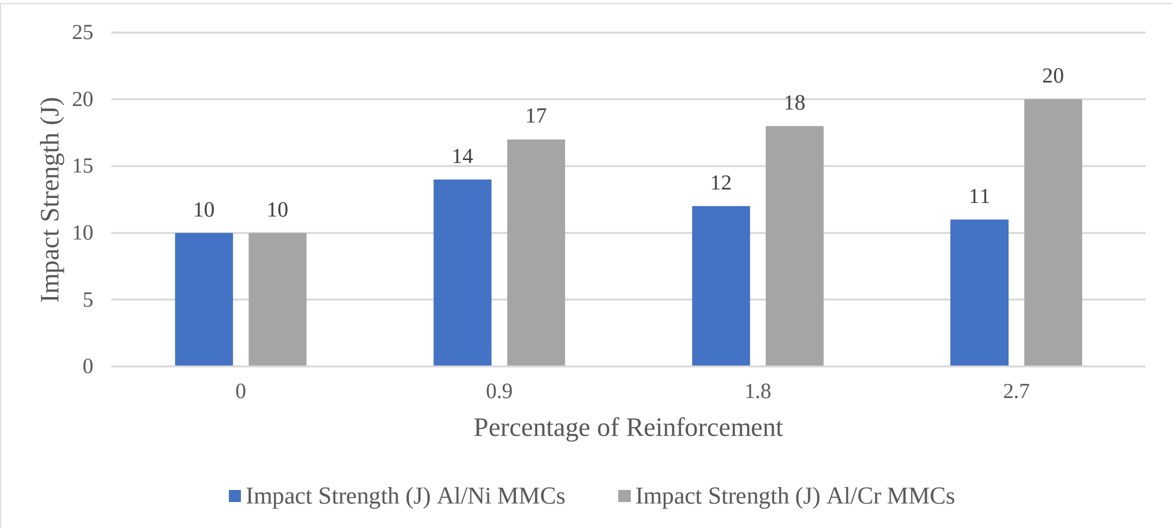

Fig.6. Influence of the Ni and Cr addition on impact strength of developed MMCs

Above bar graph represents the comparative changes in impact strength, the Ni and Cr particles have on the Al6061. The impact strength developed composite increases

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monotonically by 100%, as the Cr particles increased from 0 to 2.7 wt.%. subsequent equal addition of Ni particles of same size, do not result in such a high increase in impact strength.

4. Conclusions

When Ni or Cr are added as reinforced particles to an Al6061 matrix, the resulting MMCs have vastly different mechanical properties. The hardness improves monotonically with increasing percentages of Ni, while the flexural and impact strengths increase monotonically with increasing percentages of Cr particles. Ductility, measured in terms of percentage elongation, improved with increasing Ni and Cr particle percentages up to 0.9 wt. percent, but this effect was lost upon further addition of reinforced particles. The tensile strength of composites of both types was improved by the incorporation of the appropriate reinforcing particles. Choosing the weight percent of Ni and Cr as reinforced particles to increase most of the mechanical qualities without sacrificing too many properties requires a balance between the two extremes. When compared to Al6061/Cr MMCs, Al6061/Ni MMCs have better mechanical properties, with the exception of elongation, flexural, and impact strength. Nickel is crucial because it provides a greater strengthening impact on the final composite than Cr did. Atomic radius, lattice atomic stress, and strain all affect mechanical properties in addition to weight percentage of reinforced particles.

Conflict of Interest

The authors declare no conflict of interest.

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References

1. Ahmad, R. (2018). The Effect of Chromium Addition on Fluidity, Microstructure and Mechanical Properties of Aluminium LM6 Cast Alloy, *International Journal of Material Science and Research*, vol. 1(1), pp. 32-35.
2. Babu, S. R. K., Babu, S. V. H. and Naresh, P. (2018). Characterization of Al6061/WC/B_4C/Ti/Cr Metal Matrix Composite, *International Journal of applied Engineering Research*, vol.13(2), pp. 136-140
3. Bojinov, M., Fabricius, G., Kinnunen, G., Laitinen, T., Makela, M., Sarrio, T., Sundholm, G. and Yliniemi, K. (2002). Transpaasive Dissolution of Ni-Cr alloys in Sulphate Solutions- Comparison Between a Model Alloy and Industrial Alloy, *Electrochemica Acta*, vol. 47(11), pp. 1697-1712.
4. Kumar, G. B. V., Rao, C. S. P. and Selvaraj, N. (2011). Mechanical and Tribological Behaviour of Particulate Reinforced Aluminum Metal Matrix Composites-A Review, *Journals of Minerals and Materials Characterization and Engineering*, vol. 10(1), pp. 59-91.
5. Kumar, N. N. and Kangaraj, P. (2011). Study of Mechanical Properties of Aluminum Based Hybrid Metal Matrix Composites, *International Journal of Modern Engineering Research* vol. 11, pp. 166-172.
6. Pazman, J., Madai, V., Toth, J. and Gacsi, Z. (2010). Investigations of Electroless Nickel Plated SiC Particulate in Metal Matrix composites, *Powder Metallurgy progress*, vol. 10(2), pp. 102-109.

ISSN 2063-5346

7. Ramesh, A., Prakash, J. N., Gowda, A. S. S. S. and Appaiah, S. (2009). Comparison of the Mechanical Properties of Al6061/Albite and Al6061/Graphite Metal Matrix composites, *Journal of Minerals and Materials Characterization and Engineering*, vol. 8(2), pp. 93-106.
8. Sagar, K. and Radhakrishna, L. (2017). The Influence of Nickel Addition on the Mechanical Properties of AA6061 Fabricated by Stir Casting, *International Journal of Materials Science*, vol. 12, pp. 617-625.
9. Satheesh, M and Pugazhvadivu, M. (2018). Flexural Strength Behavior of Al 6061 Matrix Reinforced with SiC and Coconut Shell Ash, *SSRG International Journal of Mechanical Engineering*, vol. 1, pp. 12-15.
10. Swamy, A. R. K., Ramesha, A., Kumar, G. B. V. and Prakash, J. N. (2011). Effect of Particulate Reinforcements on the Mechanical Properties of Al6061-WC and Al6061-Gr MMCs, *Journal of Minerals & Materials Characterization and Engineering*, vol. 10(12), pp. 1141-1152.
11. Wong, W. L. E., Gupta, M. and Lim, C. Y. H. (2006). Synthesis and Characterization of Hybrid Aluminum Composites Reinforced with Ni Particulates and Interconnected Fe Mesh, *Solid state Phenomena*, vol.111, pp. 39-42.