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Enhancing the Tribological Behavior of Hybrid Al6061 Metal Matrix Composites through the incorporation of Nickel and Chromium Nanoparticles

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Abstract— *In this work, the influence of addition of nickel and chromium micron/nano particles on the tribological behavior of developed Al6061 hybrid metal matrix composites has been identified. In the first category Al6061 based hybrid metal matrix composite reinforced with x wt.% of nickel (x=0, 0.9, 1.8 and 2.7) and same wt.% of chromium micron size particles were fabricated throughcost- effective stir casting technique. In the second category Al6061 based hybrid nano metal matrix composites reinforced with y wt.% of nickel(y=0, 0.6 and 1.2) and same wt.% of chromium nanoparticles developed through same technique. Graphite and magnesium micron/nano size particles added to improve self-lubrication property and wettability respectively. The wear rate of developed composites has been tested on pin-on-disc experimental set up at defined speed 500 RPM, sliding distance 1000 m and variable load 10N, 20N & 30N. The reduction of wear rate of Al6061/1.8Ni/1.8Cr hybrid metal matrix composite and Al6061/0.6Ni$_{np}$/0.6Cr$_{np}$ hybrid nano metal matrix composite 37.1% and 76% w.r.to Al6061 alloy. The results revealed that there is significant improvement in wear resistance or decrement in wear rate of hybrid nano metal matrix compositesas compared to hybrid metal matrix composite and Al6061 alloy. An attempt made in this work to provide information for superior tribological behavior of hybrid nano metal matrix composites.*

Keywords— ***Al6061, hybrid metal matrix composites, nickel, chromium, nanoparticles, wear rate.***

I. INTRODUCTION

Aluminum (Al) alloy has many applications in industries due to its excellent strength, low strength to weight ratio, good thermal properties and resistance in corrosion. On the other hand, Al alloys have low resistance to wear. The desired properties of the Al alloy can be achieved through hybrid metal matrix composites reinforced with nano size particles. Reinforcement particles at micro or nano scale level can be placed inside it, creating a new aluminum based composite material. Introducing of two or more than two filler materials or reinforced particles developed a composite with superior properties as compared monolithic metal or alloy and single type particulate reinforced metal matric composites (Ramesh et al. 2009). Enhancement in tribological behavior of developed MMCs reinforced with single type particles have been reported by various investigators.

Sharifi and Karimzadeh (2011) studied the mechanical and tribological behavior of fabricated pure aluminum-based metal matrix composite reinforced with different weight percentage (5, 10 and 15) of B_4C nanoparticles by powder metallurgy technique. By increasing the weight percentage of B_4C nanoparticles the wear resistance increases continuously but optimum value observed at 15 wt. % of B_4C nanoparticles. By reduction in size of particle from micron to nano tendency of cracking of particles get reduced. Results revealed that micron size reinforced hybrid composites are inferior in wear properties w.r.to nano size reinforced hybrid composites.

Premnath et al. (2014) examined the influence of reinforced particles on the wear behavior of aluminum metal matrix composite. They fabricated Al6061 based composites reinforced with varying weight fraction (5%, 10% and 15%) of alumina and fixed weight fraction (5%) of graphite. Graphite is added to improve self-lubricating property hence it affects the wear behavior of developed composite. Results concluded that wear resistance increased with increasing weight percentage of silica and which is dominated by the load and followed by speed and composition of reinforcement.

Nassar and Nassar (2017) studied the mechanical properties of Al/TiO_2 nano composites. Uniform distribution of TiO_2 nano particles and absence of cluster formation observed. Wear resistance increased with increasing the volume percentage of reinforced nano particles.

Umanath et al. (2011) examined the wear behavior of Al6061 based composite reinforced with varying volume fraction (5-25%) in steps of 5% of Al_2O_3 and SiC particles. Wear test conducted at constant speed and distance 2.09m/s and 1884m respectively at loads 3kgf, 4kgf and 5kgf of developed composites on pin-on-disc apparatus. Authors reported that wear rate decreased with increasing volume fraction of reinforcement.

Mohapatra et al. (2015) compared the tribological behavior between developed Al6061 alloy-based metal matrix composite reinforced with micron and nano size aluminum oxide with fixed amount of titanium.MMCs reinforced with nano size particulate of aluminum oxide shows better wear resistance w.r.to MMCs reinforced with micron size particulate of aluminum oxide and base alloy i.e. Al6061.

Reddy et al. (2019) carried out an investigation on wear behavior of Al6061 based MMC reinforced with fixed wt.% 2 of SiC nano particles of size 50 nm and X wt. % of Gr particles of size 500 nm (X=0, 0.5, 1, 1.5, 2, 3). Wear rate decreased monotonically with addition of SiC particles and Gr particle up to 2 wt.% afterwards wear rate increases. Results revealed that maximum microhardness 91 HV for Al6061/2SiC nano composite and maximum reduction 73% in wear rate observed for Al6061/2SiC/2Gr nano hybrid composite as compared to Al6061 matrix.

It is observed that hybrid nano metal matrix composites are in better choice as compared to nano metal matrix composites, hybrid metal matrix composites and monolithic metals or alloys.Therefore, more attention is focused on cheap transition metals like nickel and chromium micron/nano size particles to enhance tribological properties. In the present study, the influence of nickel and chromium micron/nano size particles addition on the tribological properties of Al6061 developed by liquid casting technique were analyzed. Graphite/Graphene used to improve self-lubrication property whereas magnesium used to improve wettability of developed HMMCs and HNMMCs.

II. MATERIALS AND METHODS

For the current work Al6061 alloy was chosen as a base material or matrix because of its vast applications.Table 1 shows the chemical composition of Al6061.

Table 1. Chemical composition of Al 6061alloy

Element	Mg	Si	Fe	Cr	Zn	Pb	Cu	Mn	Ti	Ni	Sn	Al
Wt. %	0.81	0.45	0.39	0.25	0.25	0.24	0.24	0.14	0.15	0.05	0.001	Bal.

In case of hybrid metal matrix composites nickel and chromium micron size particles were used as reinforcement due to better strengthening effect and corrosion resistance respectively. Graphite and magnesium particles of micron size added in fixed weight fraction to improve self-lubrication property and wettability respectively. Table 2 shows the properties of micron size reinforced particles.

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Table 2. Properties of micron size reinforced particles

Case A: Al6061 Reinforced with Micron Size Particles				
Reinforcement	Nickel	Chromium	Graphite	Magnesium
Images				
Purity	99.16%	99.60%	99.50%	99.87%
Particle Size	44 µm	44 µm	37 µm	149 µm
Melting Point	1450°C	1900°C	3652°C	650°C

In case of hybrid nano metal matrix composite, nickel and chromium nano particles were used for reinforcement. Whereas, graphene and magnesium nanoparticles were added in fixed weight fraction. Table 3. Shows the properties on nano sized reinforced particles

Table 3. Properties of nano size reinforced particles

Case B: Al6061 Reinforced with Nano Size Particles				
Reinforcement	Nickel	Chromium	Graphite	Magnesium
Images				
Purity	>99 %	>99.9%	>99%	>99.9%
Particle Size	30-50 nm	30-50 nm	5-10 nm	30-50 nm
Melting Point	1453°C	1875°C	3550°C	2852°C

Table 4. Planning for fabrication of MMCs reinforced with micron size particles

Category (C)	**Sample No.**	**Al6061**		**Nickel (Ni)**		**Chromium (Cr)**		**Graphite (Gr)**		**Magnesium (Mg)**	
		gm	**%**	**gm**	**%**	**gm**	**%**	**gm**	**%**	**gm**	**%**
C1 (Different wt. % of Ni & Cr micron particles)	SM1	473	94.6	4.5	0.9	4.5	0.9	13.5	2.7	4.5	0.9
	SM2	464	92.8	9.0	1.8	9.0	1.8	13.5	2.7	4.5	0.9
	SM3	455	91.0	13.5	2.7	13.5	2.7	13.5	2.7	4.5	0.9

Table 5. Planning for fabrication of MMCs reinforced with nano size particles

Category (C)	Sample No.	Al6061		Nickel (Ni)		Chromium (Cr)		Graphite (Gr)		Magnesium (Mg)	
		gm	%	gm	%	gm	%	gm	%	gm	%
C2 (Different wt. % of Ni & Cr nanoparticle)	SN1	488.5	97.7	3	0.6	3	0.6	3	0.6	2.5	0.5
	SN2	485.5	97.1	3	0.6	6	1.2	3	0.6	2.5	0.5
	SN3	485.5	97.1	6	1.2	3	0.6	3	0.6	2.5	0.5
	SN4	482.5	96.5	6	1.2	6	1.2	3	0.6	2.5	0.5

Stir casting is a cost-effective technique for the development of Al6061 based HMMCs and NHMMCs as per table 4 and 5 at casting temperature 750˚C and stirring for 15-20 mins at 400 rpm through an automated stir casting set up. After solidification, specimens were prepared as per ASTM standards for wear test. The specimens for wear test were tested on pin-on-disc apparatus at: normal load 10 N, 20Nand30N, speed 500 RPM and sliding distance 1000 m.

III. RESULTS AND DISCUSSIONS

3.1. Wear Rate for Hybrid Metal Matrix Composites (HMMCs)

Table 6 shows the results obtained during wear test of developed HMMCs. Wear rate was calculated for different weight fraction of Ni and Cr reinforced micron size particles.

Table 6. Wear rate for developed MMCs reinforced with micron size particles

Category C	Sample No.	Composition Designation	Speed (RPM)	Distance (m)	Load (N)	Wear Rate (10^{-3} mm^3/Nm)
C0 Base alloy	SM0	Al6061	500	1000	10	0.52456
					20	0.5632
					30	0.63212
C1 Different weight % of Ni and Cr micron particles	SM1	Al6061/0.9Ni/0.9Cr	500	100	10	0.3853
					20	0.44221
					30	0.4983
	SM2	Al6061/1.8Ni/1.8Cr	500	1000	10	0.32994
					20	0.38734
					30	0.45423
	SM3	Al6061/2.7Ni/2.7Cr	500	1000	10	0.60452
					20	0.68354
					30	0.8868

Figure 1 shows that wear rate decreased by adding Ni and Cr from 0 wt.% to 1.8 wt.% as reinforced particle to Al6061. further addition of reinforced particles wear rate drastically increased even greater than casted Al6061. Wear resistance monotonically decreased by increasing the load. The optimum result observed for Al6061/1.8 Ni/1.8 Cr with wear rate $0.32994x10^{-3}mm^3$/N.m at 10 N load. Similar behavior of results were obtained by Suresh and Moorthi (2013) when they performed tests on metal matrix comosites. HMMCs have better wear resistance than that of MMCs.

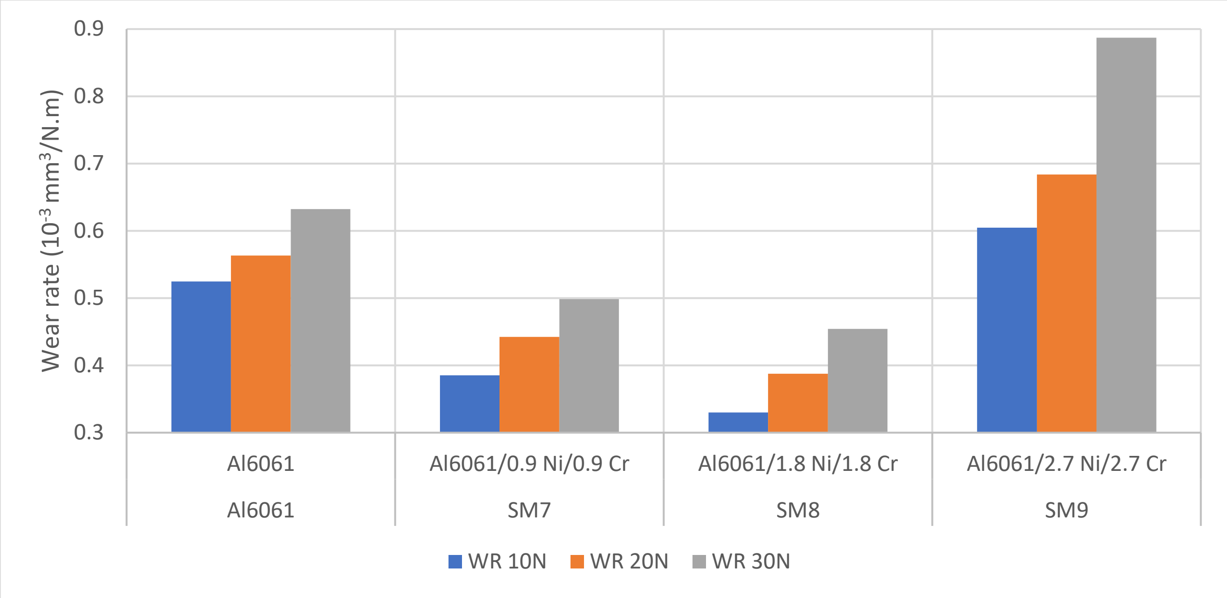

Fig.1: Variation in wear rate of Al6061 and Al6061/Ni/Cr HMMCs

The reinforcement of Ni and Cr particles strengthens the Al6061 matrix and improve the tribological behavior. Hard reinforced particles can be responsible to improve hardness hence reduction in wear rate The decrease in wear rate and enhancement in wear resistance due to uniform distribution of reinforced particles in Al6061, wettability is responsible for this. Mg addition in fixed weight percentage improve the surface wetting of MMC (kumar et al., 2011). Gr is added in fixed weight percentage to improve self lubricating property, which reduces the contact area b/w sliding pairs hence the wear rate decreases. Wear rate suddenly increased due to poor bonding between matrix and reinforced particles.

3.2. Wear Rate for Hybrid Nano Metal Matrix Composites (HNMMCs)

Table 7 shows the results obtained during wear test of developed HNMMCs. Wear rate was calculated for different weight fraction of Ni and Cr reinforced nano size particles.

Table 7. Wear rate for developed NMMCs reinforced with nano size particles

Category (C)	Sample No.	Composition Designation	Speed (RPM)	Distance (m)	Load (N)	Wear Rate (10^{-3} mm^3/Nm)
C2 Different wt.% of Ni and Cr nanoparticles	SN1	$Al6061/0.6Ni_{np}/0.6Cr_{np}$	500	1000	10	0.12600
					20	0.15632
					30	0.17162
	SN2	$Al6061/0.6Ni_{np}/1.2Cr_{np}$	500	1000	10	0.18064
					20	0.21367
					30	0.24378
	SN3	$Al6061/1.2Ni_{np}/ 0.6Cr_{np}$	500	1000	10	0.22430
					20	0.25267
					30	0.28276
	SN4	$Al6061/1.2Ni_{np}/ 1.2Cr_{np}$	500	1000	10	0.25432
					20	0.32340
					30	0.38453

Figure 2 shows the change of wear resistance and wear rate for casted Al6061, Al6061/1.8 Ni /1.8 Cr MMC and Al6061/Ni/Cr NMMCs w.r.to applied load and wt.% of reinforced nanoparticles. Wear rate reduced whereas wear resistance improved by adding minimal amount of Ni nanoparticles (0.6 wt.%) and Cr nanoparticles (0.6 wt.%) to Al6061.Wear resistance decreased by increasing the applied load. Wear rate increased if reinforced particle in developed composite higher than 0.6 wt.% but having lower value than that of casted Al6061, Al6061/1.8 Ni /1.8 Cr MMC. Graphene and MgO have better tribological properties so minimum wear rate 0.12600 x10^{-3} mm^3/N.m at 10 N load observed for Al6061/0.6Ni_{np}/0.6Cr_{np} NMMC. Muley et al. (2015) were observed similar effects of varying load at particular speed and sliding distance on NHMMCs.

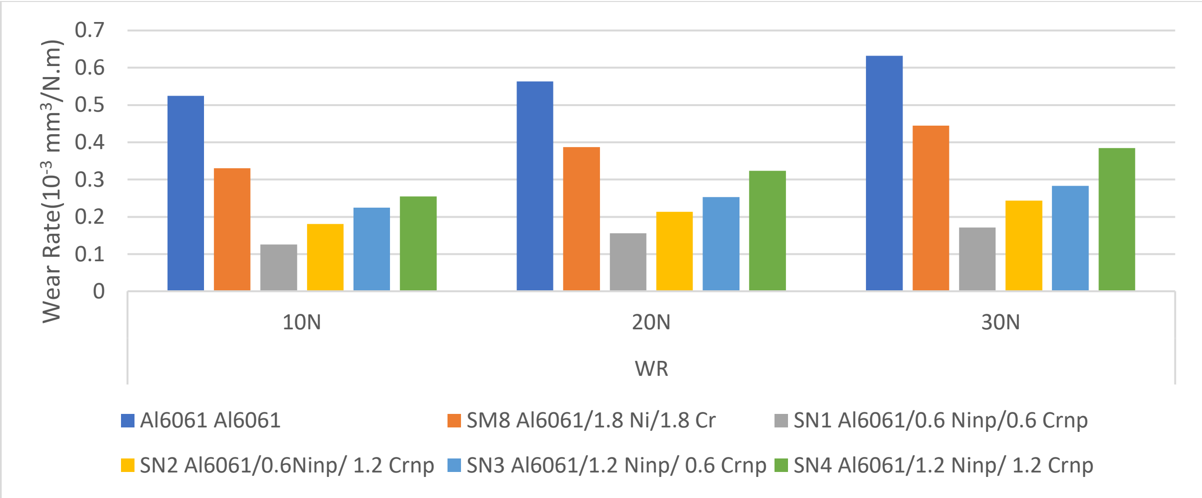

Fig.2: Variation in wear rate of Al6061, Al6061/1.8Ni/1.8Cr and Al6061/Ni_{np}/Cr_{np} HNMMCs

Addition of Ni and Cr nanoparticles positively affect the wear rate. It was observed that size of reinforced particle reduced from micron to nano the wear resistance improved due to enhancement in hardness and spacing between particles whereas cracking tendency of particle reduced by decrease in size of reinforced particles. The nano sized reinforced particles are more evenly distributed so less amount of cluster formation observed.Kumar and Xavior **(2017**) observed higher concentration of nano filler responsible for agglomeration, porosity and crack which leads to weakening of properties.Wear rate increased by increasing the weight percentage of reinforced particles in developed NMMCs due to increase in porosity and decrease in density (Muley et al., 2015).

IV. CONCLUSIONS

The reduction in wear rate of hybrid metal matrix composites and hybrid nano metal matrix composites for all applied loads observed from increasing the weight fraction up to 1.8% and 0.6% of micron and nano size reinforced particles respectively. The hybrid metal matrix composites exhibit lower wear rate at minimal concentration 0.6 wt.% of Ni and Cr nano particle and higher concentration of Ni and Cr micron size particles limited up to 1.8 wt.%. It was observed that wear rate increased by increasing the normal load. The reduction in wear rate HNMMCs and HMMCs 76% and 37.1% respectively at 10N. Al6061/0.6Ni_{np}/0.6Cr_{np} hybrid nano metal matrix composites exhibit superior tribological properties than Al6061/1.8Ni/1.8Cr hybrid metal matrix composites and monolithic Al6061 alloy. So nano hybrid metal matrix composites have better possibility to improve the tribological behavior.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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