



DETERMINATION OF HARDNESS, MECHANICAL AND WEAR PROPERTIES OF CAST AL-MG-SI ALLOY WITH VARYING NI ADDITION

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ABSTRACT

An investigation was carried out to determine the effect of Ni addition on the microstructure, hardness, tensile properties and wear rate of the cast Al-0.4Mg-8Si alloy. The Al-0.4Mg-8Si alloy was melted in an electric furnace and Ni was added to the melt in the appropriate amount. The melt was cast in a metal mould. The cast specimens were solutionised and aged. The microstructure was observed using an optical microscope and the phases present in the microstructure were identified using energy dispersive spectroscopy (EDS). The hardness, tensile properties, wear rate and coefficient of friction (CoF) were determined. The eutectic Si morphology was refined and an intermediate phase Al_3Ni was observed. The hardness and tensile properties increased, wear rate decreased and CoF remained constant for the Ni modified alloy compared to the base Al-0.4Mg-8Si alloy. It is concluded that the Ni addition significantly improves the properties of the base alloy.

Keywords: aging, aluminium alloy, hardness, mechanical properties, nickel, wear rate.

INTRODUCTION

The cast Al alloys are commonly used in automobile, industrial and aircraft applications. In many of the applications, the hardness, tensile strength and wear rate are considered as important properties. The service life of components like pistons used in automobile applications can be extended if the mechanical properties of the Al alloy currently used is enhanced. Investigations have been carried out to improve the mechanical properties of Al alloys by the alloy addition method. Researchers have added Ni, Co, Ti and Cr into Al base alloys and determined the various properties of the resulting alloys.

LITERATURE REVIEW

The influence of Co on the as cast Al-Fe-Si alloy was studied by Kilicaslan *et al.* [1] by determining the hardness and an increase in the hardness was observed after the Co addition. The effect of Co addition on melt spun Al-5Fe-25Si alloy was studied by Kilicaslan *et al.* [2] by determining the micro hardness and an increase in the microhardness was observed after the Co addition upto 5wt%. The effect of Ti addition into as cast Al-Mg alloy was studied by Elhadari *et al.* [3] and they have observed an increased ultimate tensile strength (UTS) and yield strength (YS) for the modified alloy. The Ti addition into as cast Al-Mg alloy was studied by Liu *et al.* [4] and found an increased hardness, UTS and YS after the addition. They have also observed that the Ti addition also lead to the refinement of grains. The effect of Ti addition into as cast Al-Si alloy was studied by Zeren *et al.* [5] and found an increase in the hardness due to the formation of the flake like intermediate phase. The effect of Ti addition into as cast Al-Cu-Mg alloy was studied by Kamali *et al.* [6] and found an increase in the hardness and UTS after the addition where as the % elongation (%EL) remained a constant. The effect of Ti addition into as cast Al-Si alloy was reported by Saheb *et al.* [7] and found an increase in

the hardness after the addition due to the formation of the flake shaped Al_3Ti . The effect of Cr addition into as cast Al-Si-Fe alloy was studied by Hong *et al.* [8] and found an increase in the tensile strength after the addition. The author also observed Si particles which were distributed evenly in the microstructure of the modified alloy. The effect of Ni addition into Al alloy was studied by Petrik [9] and observed an increase in the hardness for the modified alloy. An increase in the hardness and tensile properties for the Ni added alloy was observed by Naeem *et al.* [10] while studying the effect of Ni addition into as cast Al-Cu alloy. The effect of Ni addition to the as cast Al-Si alloy was studied by Li *et al.* [11] and found the formation of intermediate compound containing Ni. The effect of Ni addition to the as cast Al-Cu alloy was reported by Naeem *et al.* [12] and found an increase in the hardness and tensile properties for the modified alloy after aging. The effect of Ni addition (2wt%) was studied by Hossain *et al.* [13] on the as cast Al-6Si-0.5Mg alloy and an increased tensile strength was observed after the alloy addition.

From the review of literature, it is observed that no study is carried out regarding the effect of varying Ni content on the mechanical properties of the Al-0.4Mg-8Si alloy. Ni is considered to be an important element that is likely to improve the properties of Al-0.4Mg-8Si alloy. It is to be noted that the cast Al-0.4Mg-8Si alloy is used in many critical applications. Hence the present investigation is carried out to determine the effect of varying Ni content on the following mechanical properties of Al-0.4Mg-8Si alloy. 1. Microstructure. 2. Hardness. 3. Tensile properties (UTS, YS, %EL). 4. Wear rate. 5. CoF. Further, the impact of Ni addition on the aging of the Al-0.4Mg-8Si alloy is also evaluated in this study. The type of the intermediate phase that forms during solidification of the Ni added alloy is also investigated in this study.



EXPERIMENTAL PROCEDURE

An electric resistance muffle furnace was used to melt the Al-0.4Mg-8Si ingot and Ni was added to the melt

in the appropriate amount (2, 4, 6, 8 and 10wt %). The resultant 6 alloy compositions are listed in Table-1.

Table- 1. Chemical composition of the alloys studied.

Alloy number	Al (wt%)	Si (wt%)	Mg (wt%)	Ni (wt%)
1	Bal.	8	0.4	0
2	Bal.	8	0.4	2
3	Bal.	8	0.4	4
4	Bal.	8	0.4	6
5	Bal.	8	0.4	8
6	Bal.	8	0.4	10

The melt was cast into metal mould to obtain rod shaped specimens. Test specimens were solution treated at 537°C for 12 Hr and then quenched in water. The quenched specimens were aged at 155°C for 3 Hrs. The microstructure was observed using an optical microscope. Vicker's microhardness tester was used for measuring the hardness (Load: 100gF, Time: 15 sec) (ASTM E-384 std.). Scanning electron microscope (SEM) and EDS results were used to identify the intermediate phase present in the microstructure. The tensile specimens were machined from the heat treated rods and the tensile test was carried out using a Tinius Olsen universal testing machine (ASTM E-4 std.). The wear test was carried out on a pin-on-disc wear testing unit (Load: 20 N, Speed: 424 rpm, Track diameter: 110 mm, Time: 10 min) (ASTM G-99 STD.).

RESULTS AND DISCUSSIONS

MICROSTRUCTURE

Figure-1 shows the microstructure of Al-0.4Mg-8Si base alloy. It is observed that the eutectic Si morphology is elongated in the base alloy. Figure-2 shows the microstructure of solutionised Al-0.4Mg-8Si-2Ni alloy. The eutectic Si morphology is particle shaped in Figure-2. Also the presence of particles in the microstructure indicates the presence of an intermediate phase in the solutionised alloy. Figure-3 shows the microstructure of aged Al-0.4Mg-8Si-2Ni alloy. The eutectic Si morphology is seen to be particle shaped in Figure-3 also. Thus it is observed that the eutectic Si morphology is refined by the Ni addition. Similarly for Al-Mg-Si-xNi (x=4, 6, 8 and 10) alloys, the eutectic Si morphology changes from elongated to particle shaped by the Ni addition. The Co addition to as cast Al-Fe-Si alloy reduces the size of the eutectic Si phase as reported by Kilicaslan *et al.* [1]. Based on the above findings, it can be concluded that, the Ni addition also refines the eutectic Si morphology of Al-0.4Mg-8Si cast alloy.



Figure-1. Microstructure of Al-0.4Mg-8Si Alloy.

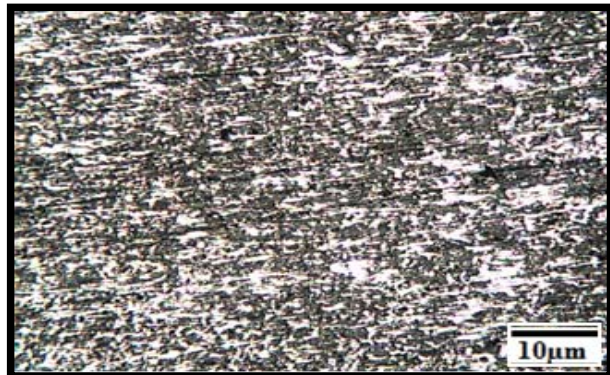


Figure-2. Microstructure of solutionised Al-0.4Mg-8Si-2Ni Alloy



Figure-3. Microstructure of aged Al-0.4Mg-8Si-2Ni alloy.

INTERMEDIATE PHASE FORMATION

The SEM image of Al-0.4Mg-8Si-2Ni alloy is shown in Figure-4. The white particles distributed in the image shows the presence of an intermediate phase in the modified alloy. The EDS spectrum of the white particle is shown in Figure-5. It is observed from the EDS spectrum that Al and Ni are present in the white particle. The composition analysis showed that the intermediate phase is Al_3Ni . Hossain *et al.* [13] has also reported the formation of Al_3Ni intermediate phase using EDS analysis, by the Ni addition into Al-6Si-0.5Mg alloy. So it can be observed that the presence of intermediate phase can be confirmed through EDS analysis. Similarly Ti addition into Al-Si alloy leads to the formation of Al_3Ti intermediate phase as reported by Saheb *et al.* [7] and Co addition into Al-Si-Fe alloy leads to the formation of Al_3Co intermediate phase as reported by Kilicaslan *et al.* [1]. Hence from the above observations, it can be concluded that Ni addition to the base alloy leads to the formation of Al_3Ni intermediate phase during solidification. Similarly for the Al-Mg-Si-xNi (x=4, 6, 8 and 10) alloys, Al_3Ni was identified as the intermediate phase.

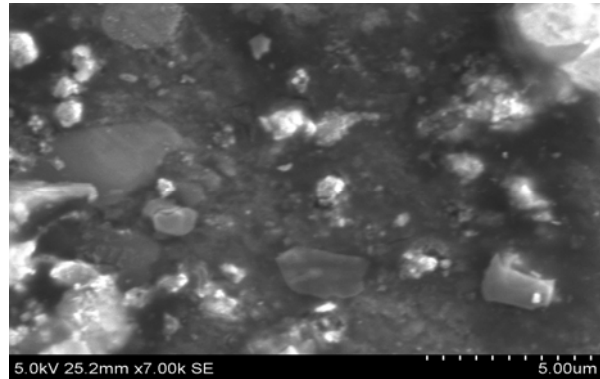


Figure-4. SEM image of Al-0.4Mg-8Si-2Ni alloy.

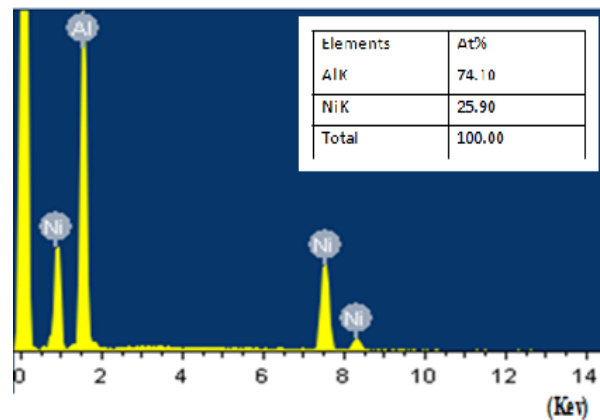


Figure-5. EDS result of Al-0.4Mg-8Si-2Ni alloy (white particle).

HARDNESS DATA

Figure-6 shows the hardness vs. wt% Ni plot for the aged conditions of Al-Mg-Si-xNi (x=0, 2, 4, 6, 8 and 10) alloy. It is observed that the hardness increases with an increase in the Ni content. This behavior is attributed to the precipitation hardening effect in the presence of Al_3Ni intermediate phase. Therefore it is concluded that the Ni addition significantly increases the hardness of the base alloy.

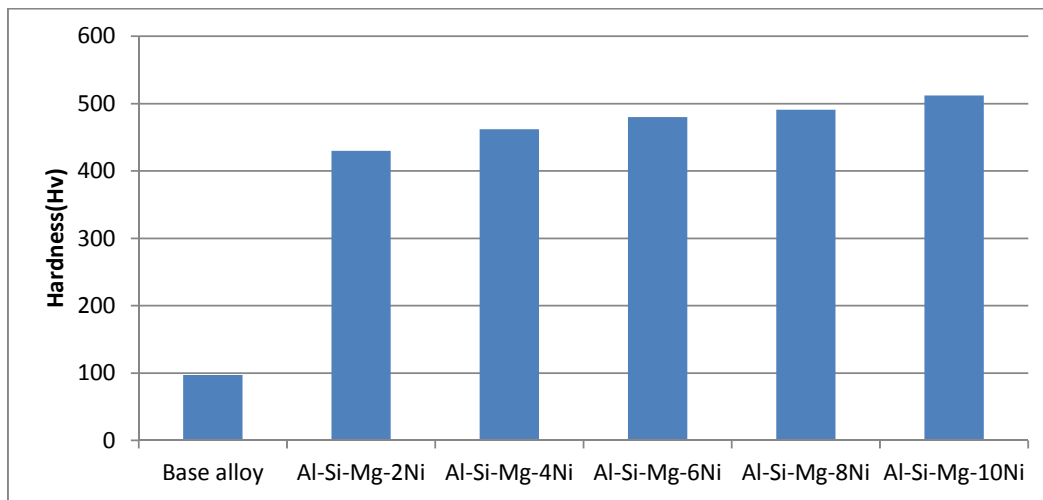


Figure-6. Hardness vs. wt% Ni (aged condition).

COMPARISON OF HARDNESS DATA

Figure-7 shows the hardness obtained in this study compared with that of other alloys from the literature. It is observed that the hardness obtained in this study, i.e., 512 Hv is higher when compared to the hardness obtained after 0.7 wt% Ni addition into Al-Fe-Si alloy as reported by Petrik [9], 0.5 wt% Ni addition into

Al-Cu alloy as reported by Naeem *et al.* [10], 0.5 wt% Ni addition into Al-Zn alloy as reported by Naeem *et al.* [12] and 5 wt% Co addition into Al-Si-Fe alloy as reported by Kilicaslan *et al.* [2]. Hence it is concluded that the hardness obtained in this study is significantly higher than those hardness values reported in the previous literature.

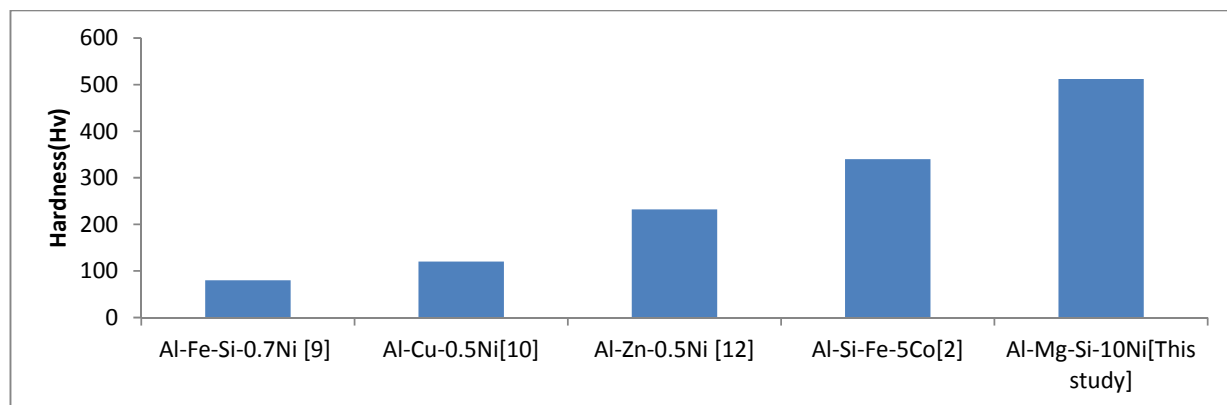


Figure-7. Comparison of hardness data.

TENSILE DATA

Figure-8 shows UTS vs. wt% Ni plot of the Al-Mg-Si-xNi (x=0, 2, 4, 6, 8 and 10) alloy in the aged condition. It is observed that the UTS increases linearly with increasing Ni content in the aged condition and this increase is attributed to the precipitation hardening effect along with the Al_3Ni second phase formation. Figure-9 shows YS vs. wt% Ni plot of the Al-Mg-Si-xNi (x=0, 2, 4, 6, 8 and 10) alloy in the aged condition. It is observed that the YS also increases linearly with increasing Ni content in the aged condition and this increase is due to the precipitation hardening effect along with the Al_3Ni intermediate phase formation. Figure-10 shows the %EL vs. wt% Ni plot for the Al-Mg-Si-xNi (x=0, 2, 4, 6, 8 and 10) alloy in the aged condition. It is observed that the %EL shows no much variation with the increasing Ni

content in the base alloy. Therefore it is concluded that the Ni addition has no detrimental effect on the %EL. An increase in the UTS and YS after the Ni addition and aging treatment in Al-Cu alloy was observed by Naeem *et al.* [10]. This improvement was due to the aging treatment and the refinement of grains. An increase in the UTS and YS was reported after the Ni addition and aging in Al-Zn alloy by Naeem *et al.* [12]. From these findings, it can be observed that the present results are consistent with the previous results from the literature and the tensile properties of cast Al alloys can be remarkably improved with the Ni addition and the aging treatment.

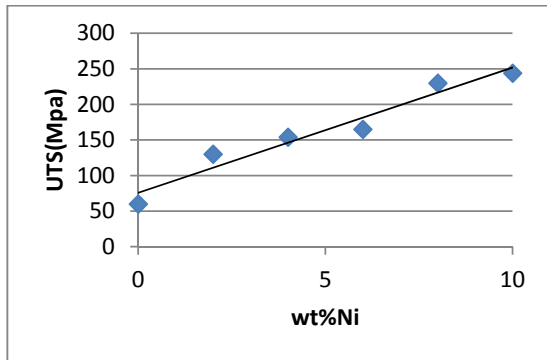


Figure-8. UTS vs. wt% Ni (aged condition).

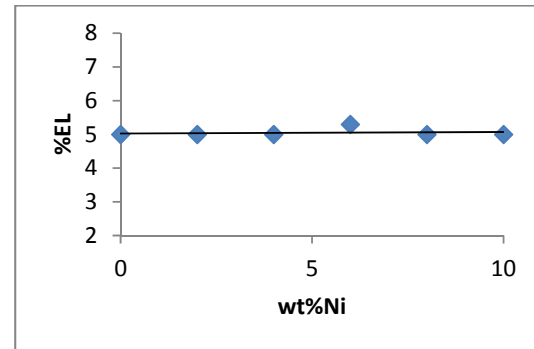


Figure-10. %EL vs. wt% Ni (aged condition).

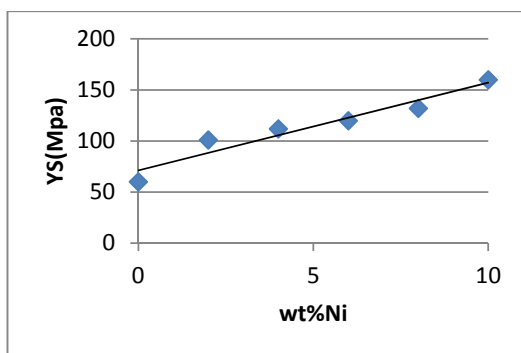


Figure-9. YS vs. wt% Ni (aged condition).

COMPARISON OF TENSILE STRENGTH DATA

Figure-11 shows the comparison of the tensile strength of Ni added alloy in this study with that of previously studied alloys. It is observed that the UTS obtained in this study, i.e., 244 MPa is higher when compared to the UTS obtained after 2 wt% Ni addition into Al-6Si alloy as reported by Hossain *et al.* [13], 20 wt% Si addition into Al alloy as reported by Hong *et al.* [8] and 0.3 wt% Ti addition into Al-4.5Cu-0.3Mg alloy as reported by Kamali *et al.* [6]. Hence it is concluded that the UTS obtained in this study is higher than those UTS values reported in the previous literature.

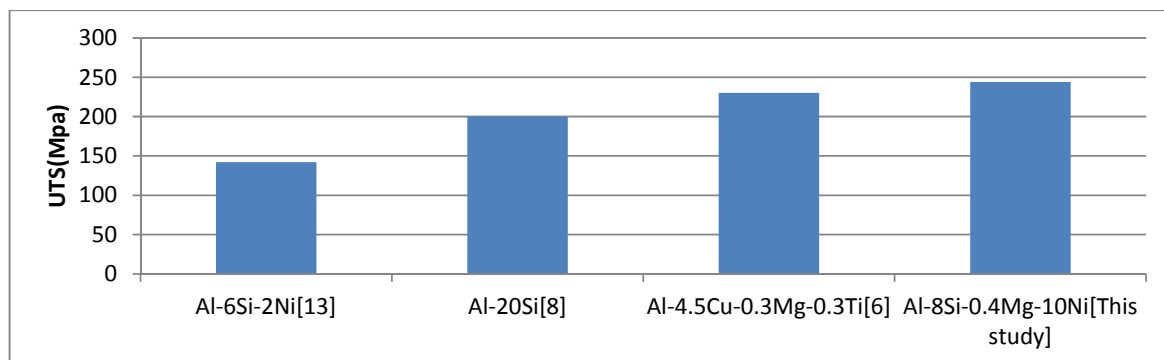


Figure-11. Comparison of tensile strength data.

WEAR DATA

Figure-12 shows the wear vs time plot for the Al-0.4Mg-8Si-2Ni alloy in the aged condition. It is observed that the wear increases linearly with time. Similarly for Al-Mg-Si-xNi (x=4, 6, 8 and 10) alloy, wear was found to increase linearly with the time. Figure-13 shows the wear rate vs wt% Ni plot for Al-Mg-Si-xNi (x=0, 2, 4, 6, 8 and 10) alloy in the aged condition. Here the wear rate is found to decrease with the increasing Ni content and this decrease is attributed to the presence of Al₃Ni intermediate phase and due to the precipitation hardening effect. Figure-14 shows the wear rate vs hardness plot for the Al-Mg-Si-xNi (x=2, 4, 6, 8 and 10) alloy. Here the wear rate is found to decrease with the hardness and this result is

found to be consistent with the Archard's wear theory [14]. Thus it can be concluded from the above observations that the Ni addition significantly reduces the wear rate of the Al-0.4Mg-8Si alloy.

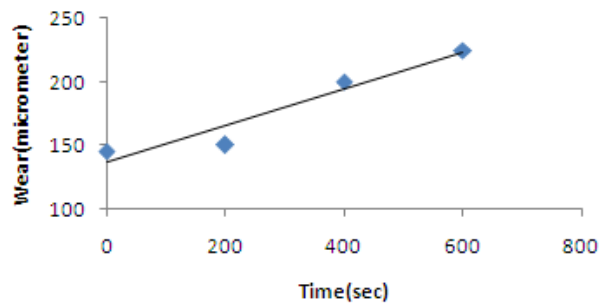


Figure-12. Wear vs. time.

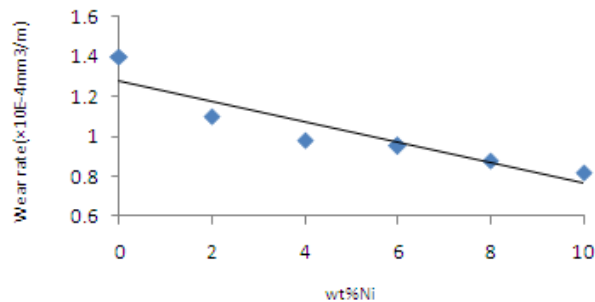


Figure-13. Wear rate vs. wt%Ni (aged condition)

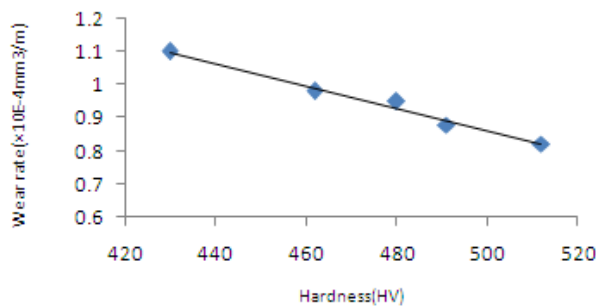


Figure-14. Wear rate vs. hardness.

COF DATA

Figure-15 shows the CoF vs wt% Ni plot for the Al-Mg-Si-xNi (x=0, 2, 4, 6, 8 and 10) alloy in the aged condition. It is observed that the CoF does not vary significantly with the increasing Ni content.

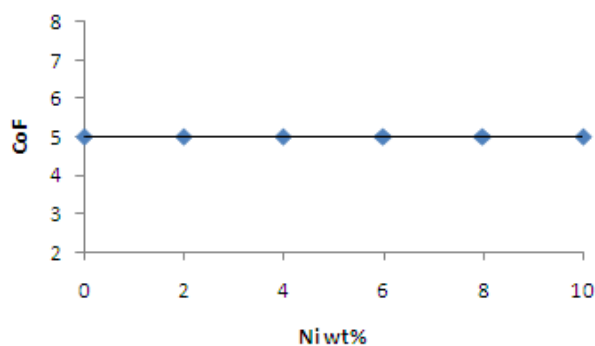


Figure-15. CoF vs. wt% Ni (aged condition).

CONCLUSIONS

It is concluded from this study that with the addition of Ni to the Al-0.4 Mg-8Si alloy, 1. Eutectic Si morphology changes from elongated to particle shaped. 2. Al₃Ni intermediate phase is formed during solidification. 3. Hardness increases. 4. UTS and YS increase and %EL remains a constant. 6. Wear rate decreases. 7. CoF remains a constant.

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