IRAQI Academic Scientific Journals

Available at https://www.iasj.net/iasj

Iraqi Academic Scientific Journals

Journal homepage:
https://journals.uokerbala.edu.iq/index.php/UOKJ

Journal of University of Kerbala

Research Article

Dry wear properties of Aluminum Alloy 6061 hardened with ceramic powders using diffusion method

Ridha Hameed Mageed , Hussein Younus Razzaq, Hussein Mohammed Hasan

Karbala Technical Institute, Al-Furat Al-Awsat Technical University,
56001, Karbala, Iraq

Article Info

Article history:

Received 13-04-2021

Received in revised form 24-05-2021

Accepted 01-08-2021

Available online 06-06-2022

Keywords:

wear resistance, diffusion temperature, diffusion time, hardness. Aluminum Alloy 6061 (AA 6061).

Abstract

Surface hardening of metals is one of the efficient ways to give the metal new mechanical properties that are not present in the original metal.

In this paper, the effect of the type and size of the ceramic powder, temperature and time on the rate of diffusion of a number of ceramic powders across the surface of the AA 6061 was studied, and thus the amount of increase in hardness and wear resistance in the surface of this alloy. Several ceramic powders were used, such as sand, metakaolin, and iron oxide, with a granular size not exceeding 74 microns.

The results of the examination of the research samples showed an increase in the values of hardness and wear resistance compared to the original sample (AA 6061without addition).

The hardness and microscopy results also showed that temperature and time have an effect on diffusion rates. This relationship was not linear, as the aspect ratio of both the hardness and wear resistance values decreased with increasing temperature diffusion time.

The results also confirmed that the hardness and wear resistance of AA 6061 samples are proportional to the hardness value of the ceramic powder scattered in it.

Corresponding Author E-mail : 1inkr.red@atu.edu.iq,2 inkr.hus@atu.edu.iq, 3hussinmohamad@atu.edu.iq
Peer review under responsibility of Iraqi Academic Scientific Journal and University of Kerbala.

Introduction

Obtaining metal alloys with specific specifications needs to know the properties of the alloy and thus choose the appropriate method to improve its properties.

Surface hardening is a technological method that aims to increase both hardness and wear resistance of metal surfaces while retaining a high-toughness core. Some thermal treatments involving solidification with a particular technique achieve that goal. There are also other techniques and methods aimed at raising the hardness of metal surfaces and reduce the friction coefficient.

Carbon, nitrogen, and cyanide are the most common materials used in surface hardening processes in industrial applications, but there is a lot of research that has used other metallic or ceramic powders to obtain hard surfaces.

Surface hardening processes can be expressed as a solid-solid diffusion process. Many variables play a role in the efficiency of the diffusion process and thus the properties of the product. Variables that greatly affect it are the specifications of the solvent and solute, temperature, and time of the diffusion, in addition to the amount of distortion in the microstructure of the solvent as a result of the diffusion of the solute in it.

Most of the research that discussed surface hardening focused on the quality and specifications of the powders used in the surface hardening process, as well as the effects of using that powder. Where we did not observe researches concerned with the study of time and temperature on the surface hardening process.

Qing Zhang found that the composite wear resistance of the Al-12Si-CuNiMg alloy reinforced by Al2O3 fiber was lower than that of the parent alloy, due to the high content of used fibers(1). Using the stir casting technology of Al6061 alloy with 5% SiC, Avinash Bhat and Ganesh Kakandikar were able to produce a new composite body with better hardness and wear resistance. (2). Sheng fang Zhang's group concluded that there is a positive relationship between slip erosion with slip velocity and load (3). Fathi et al. concluded that the deposition of nickel coated with aluminum oxide on the aluminum surface leads to an improvement in the strength, and the self-lubricating property, in addition to an increase in the efficiency of pressure transfer (4).

Tejoh Triuno and his team found that cortical hardening by carbonation if followed by quenching improves the hardness and tensile strength of aluminum7074 alloy (5). Shanmugasundaram and his team raised both the hardness and wear resistance of AA 6063 by 50% by depositing tungsten carbide on the surface of the alloy (6). Yuxin Li and his group concluded that the TiBCN content of 15% in the Ti/TiBCN coating used to coat AA7074 by laser increases the hardness of the alloy surface significantly (7).

Daniela and colleagues found that the addition of fine particles of SiC at 15% by weight of the alloy provides better wear resistance under dry slip conditions of the aluminum matrix (8).

Mahesha's group discussed slip-dry wear behavior on precipitation-reinforced stainless steel. The results indicated that load is the most important factor affecting the loss of wear volume and specific wear rate (9). Popola et al. reported the possibility of enhancing the hardness and wear resistance of aluminum alloy surface by using laser hardening technique to deposit zirconium-molybdenum powders on it. (10).

In this paper, the effect of some solid-solid diffusion phenomenon variables on the rate of diffusion of ceramic powder across the surface of AA 6061 and thus on both the hardness and wear resistance of the surface of those samples will be studied. Three types of ceramic powders were selected: sand, metakaolin, and iron oxide. Three temperatures were set depending on the melting point of the AA 6061. The third variable is a duration of diffusion , as three duration times were chosen for the diffusion process.

methodology

The work plan was based on studying the effect of ceramic powder type, temperature, and time on the diffusion rate of ceramic powder through the surface of AA 6061 samples, and the effect of these variables on the hardness and wear resistance of AA 6061 samples.

Three ceramic powders were prepared, they are high purity sand, metakaolin, and iron oxide, which were purchased from one of a scientific chemical store in Baghdad. The powders were ground and passed through a No. 200 sieve with holes measuring 74 µm. Table (1) shows the chemical analysis of these substances.

Powder particles passing through the 200 sieve contain particle sizes of that powder of 74 µm and below. Thus, a good amount of powder can be obtained, measuring less than 1 micrometer, and that quantity diffused in the metal alloy at a high rate compared to the coarse particles. A number of samples were prepared (two samples for each test) from AA 6061 with a diameter and a height of (20 * 20) mm by the lathing process, using a high-speed steel lathing pen. The cutting speed in the finishing process was 740 rpm, the cutting depth was 0.2 mm, and the feeding was done Limit it to 20% mm per cycle. Figure 1 shows some of the research samples, and table(2) shows the chemical composition of AA6061.

After preparing the samples and metal powders, the samples were placed vertically inside a metal container, then the powder was placed on the surfaces of the samples with a height of more than 2 cm to ensure an efficient diffused of fine powder particles on the surface of the AA6061. Metal container had placed inside an electric furnace as shown in Figure (2), and the furnace was heated to the required temperature, and samples were kept at that temperature for a specified period of time. Turn off the furnace and keep the samples inside of it until the furnace temperature had reach to room temperature.

Table(1) Chemical composition of ceramic powders (wt%)

Elements	SiO_2	Al_2O_3	Fe_2O_3	CaO	TiO_2	MgO	K_2O
Sand	98.43	1.21	0.074	0.1	trace	trace	Trace
Metakaolin	52.49	40.34	1.48	1.03	1.41	0.65	0.43
Iron oxide	0.18	0.04	99.14	0.06	trace	trace	Trace

Table(2) Chemical composition of AA6061(wt%)

Elements	Fe	Si	Mg	Cu	Cr	Others	Al	Hardness
%	0.04	0.63	1.04	0.23	0.21	0.3	balance	40 (HRC)

Fig (1)Research specimens

Three temperatures (410.470.525)°C were applied, depending on the AA6060's melting temperature of 583 °C, as (0.9, 0.8, 0.7) was adopted from its melting temperature. Three time periods (3, 6, 9) hours were also applied for heating the samples.

The samples were taken out of the furnace. To remove the powder sticking to the surface of the samples, it was operated by turning and fine grinding process to reach the basic dimensions of the samples (20 * 20) mm.

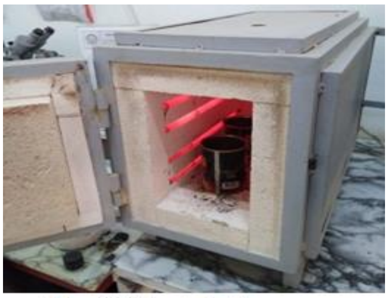

Fig (2)Electric furnace

Figure (3) hardness test

The hardness, wear resistance and microscopy tests were performed as follows:

Hardness testing: This testing was performed using a Rockwell hardness test As shown in Figure (3).

Wear resistance test: A pin device was used on the disc shown in Fig. 4 to perform this test, where the test was done after fixing the device’s speed at (150) rpm, the test time at (5) min. and the applied load at (20) Newton. After finding the lost weight of the samples, the lost volume was calculated.

Microscopy: After grinding, polishing and etching of the research samples, the Microscopy was performed with a magnification strength of 50,100,1000 times.

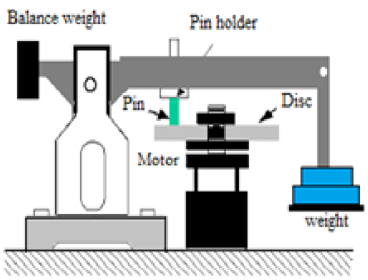

Fig (4) Wear resistance test

Results and Discussion

What engineering materials have of certain mechanical properties because of the nature of those materials and the nature of the links that link them, and the amount of distortion in the structure of their crystal lattice works to change their mechanical properties. The presence of a particle within a certain structure of a substance may lead to its interaction with the atoms of that substance to form a solid solution or a chemical compound, and may lead to a distortion of the crystal structure of that substance. All these variables lead to raising the hardness and wear resistance.

The wear resistance results in Figure (5) generally show an increase in the wear resistance with increasing temperature of the samples. These results show that the rate of powder diffusion inside the samples increases with increasing temperature. The figure also showed the effect of powder type on wear resistance, where samples containing sand showed the highest wear resistance, then metakaolin and iron oxide. The reason for this is that the hardness of sand is higher than the rest, and the reason may be the higher rates of sand diffusion on the surface of the alloy compared to metakaolin and iron oxide. Also, the hardness of metakaolin is higher than that of iron oxide. Figure (5) also showed the convergence of the wear resistance results for each of the aluminum samples containing iron oxide and metakaolin compared to the wear resistance results for the aluminum samples containing sand, which showed higher hardness compared to the other powders. The rates of increase in wear resistance with increasing diffusion temperature were not linear, as Figure (5) showed a decrease in the rate of increase in wear resistance with increasing temperature at most.

The wear resistance results in Figure (6) showed a higher wear resistance with increased heating time. We conclude from this, that the rate of powder propagation within the aluminum sample increases with increasing heating time. Figure (6) also showed the effect of the powder type on wear resistance, as the type of powder had the same effect as shown in Figure (5). The relationship between heating time (diffusion time) and the wear resistance was semi-linear.

The hardness results in Figure (7) showed an increase in the hardness of the research samples with increasing temperature. We conclude from these results that the rate of powder diffusion inside the aluminum sample increases with increasing temperature.

The figure also shows the effect of powder type on hardness. The samples containing sand were given the highest hardness, then metakaolin, and iron oxide.

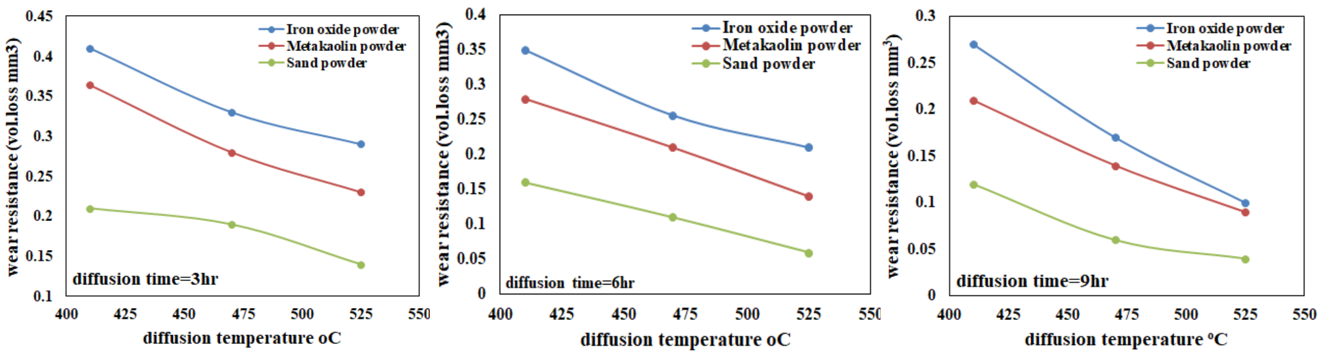

Fig (5) Effect of diffusion temperature on the wear resistance

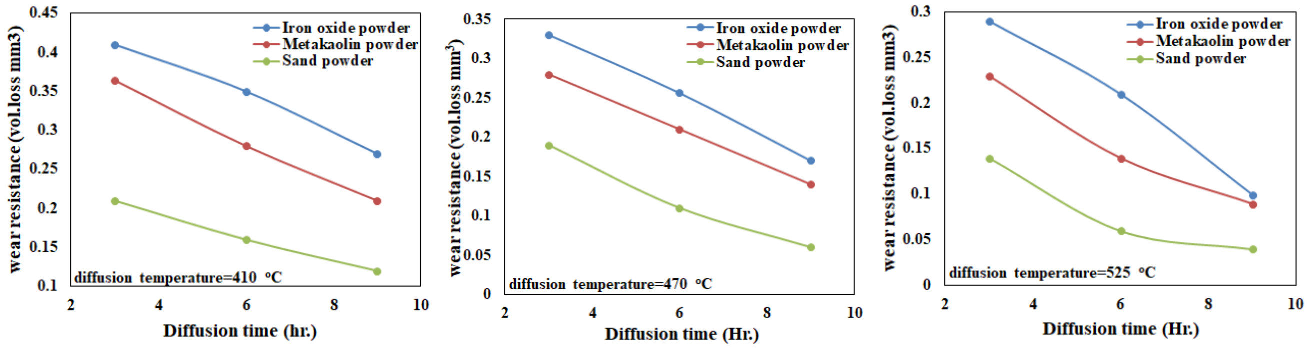

Fig (6) effect of diffusion time on wear resistance

Figure (7) also showed the approximation of the hardness results for each of the aluminum samples containing iron oxide and metakaolin compared to the hardness results for the aluminum samples containing sand, because the hardness of sand is higher than that of other powders. This increase in the hardness of the aluminum samples containing sand may have occurred due to the fact that the rate of diffusion of sand powder in the alloy is higher than the rate of diffusion of the rest of the powders. The deformation in the crystal lattice of the alloy surface did not provide us with the appropriate tools to examine it. The rates of hardness increase with increasing diffusion temperature were not linear, as Figure (7) showed a decrease in the rate of hardness increase with increasing temperature at most.

The results of microscopic examination of research samples (produced at 525^{o}C and 9hr) confirm the diffusion of powders in it, where we notice the appearance of areas with traces of the presence of powders in samples containing additives compared to the sample without addition, especially at the low magnification force.

The results of the microscopy also showed some observations

1- An aluminum alloy containing silicon oxide showed oxide beads as scattered bright spots at low magnification (50 times). This result confirms that some oxide grains remain in their spherical shape without being affected by heat and have not been sintered. As for the medium and large magnification strength, a remarkable homogeneity appeared in the surface of the alloy, through this it can be inferred that the interaction of very fine particles with the elements in the alloy to form new phases.

Small irregular shapes are observed on the surface of the aluminum alloy containing iron oxide. Luminous areas also appear elsewhere on the sample surface. This can be explained by the possibility of sintering the oxide (semi-melting) which led to its spread in

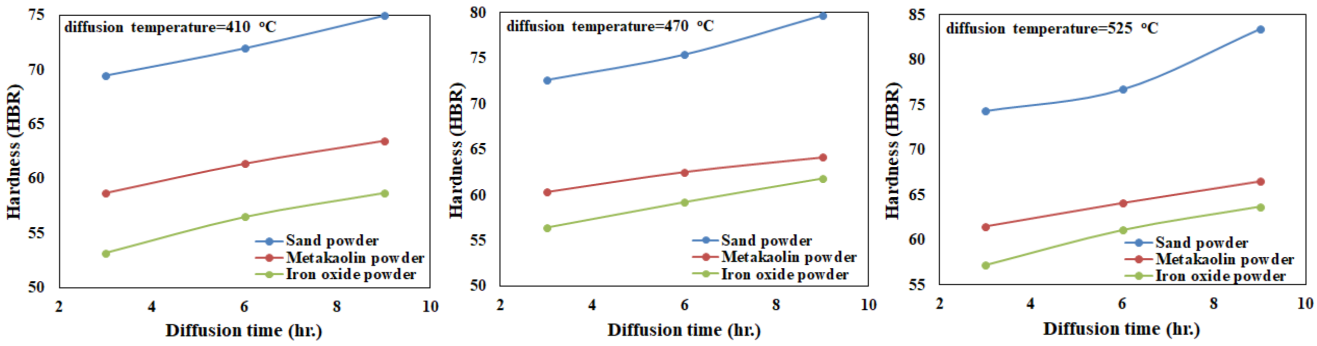

Fig (7) effect of diffusion time on Hardness

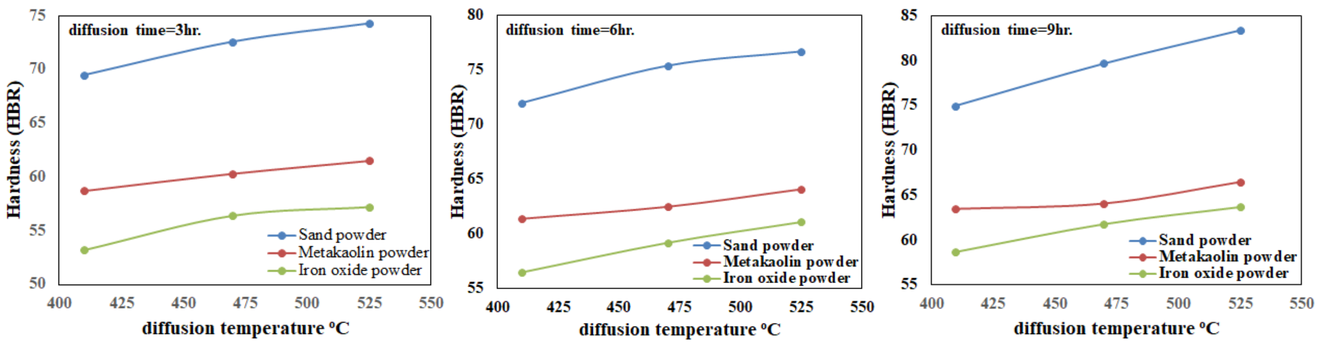

Fig (8) effect of diffusion temperature on the hardness

2- a wider area due to its low melting point. The presence of luminous areas on the surface of the aluminum alloy can also be explained by visualizing a partial decrease in the iron oxide fraction as a result of its reduction by aluminum, leaving the iron particles dispersed. To prove this, we need other tests.
3- The results of microscopic examination of the aluminum alloy sample containing metakaolin showed the presence of dark areas on the surface of that sample, similar to those that appeared on the surface of the aluminum sample containing iron oxide, but it took more space. This means that metakaolin is able to Sintering more than iron oxide. As for a large magnification strength, a remarkable homogeneity appeared in the surface of the alloy.

Generally, the results of the microscopic examination confirm the diffusion of additives in the depth of the samples of aluminum 6061 alloy.

Conclusion

The research results confirm a number of observations:

1- The possibility of using oxides powders significantly to improve both the hardness and wear resistance of the aluminum alloy 6061.
2- The rate of diffusion of oxides powders increases with increasing temperature and spread time.
3- The hardness and wear resistance of aluminum alloy 6061 increase with the increasing of powder hardness.
4- It is possible to develop the surface properties of metals and alloys by using the diffusion method instead of casting with ceramic powders.

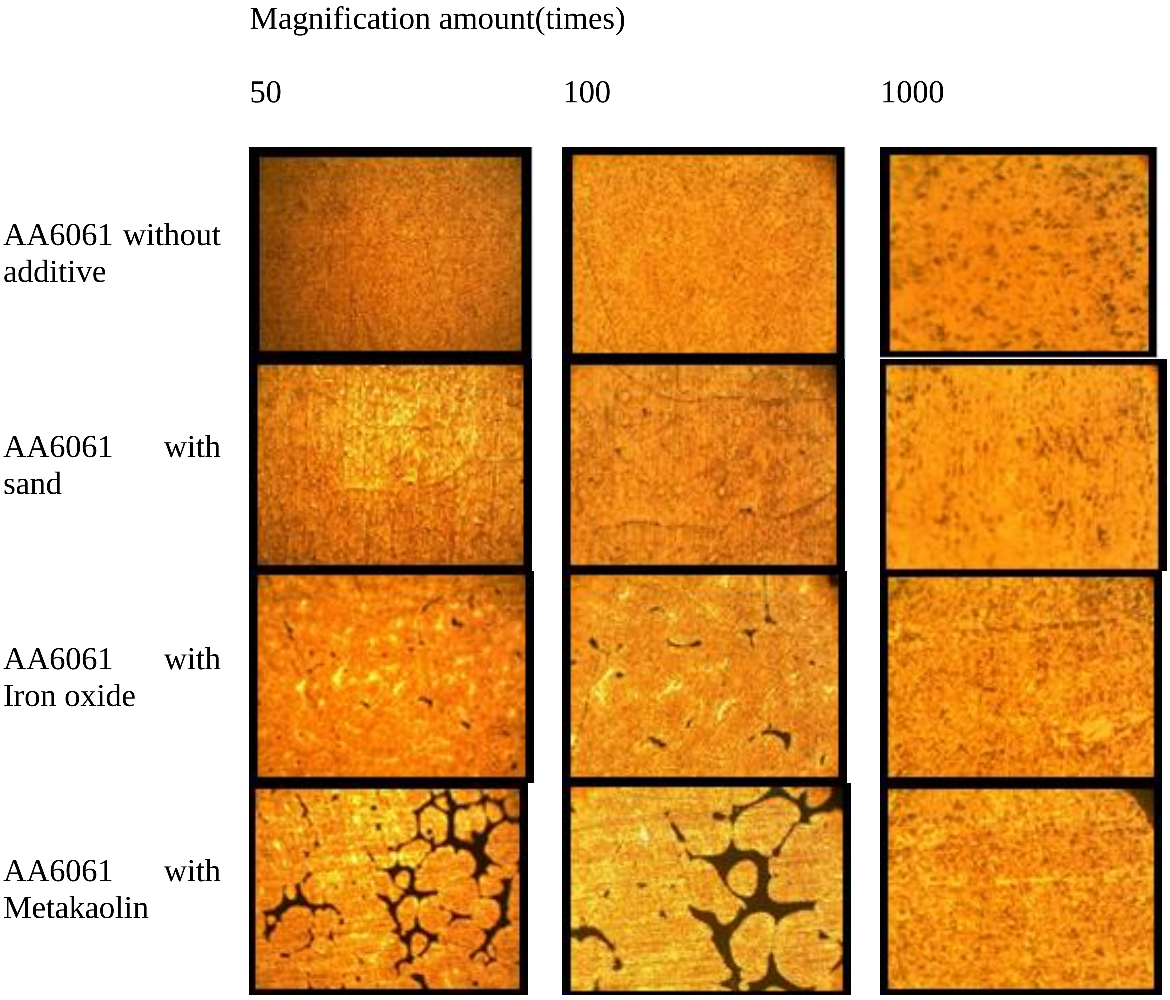

Fig (9) results of microscopic examination of research samples

Acknowledgments :At the conclusion of the work, the researchers would like to thank everyone who contributed to providing support for the completion of the research, especially the Metallurgical Laboratory at the College of Engineering at Karbala University for their assistance in the microscopic examination. As well as the laboratories and workshops unit at the Karbala Technical Institute for their contribution to the preparation of research samples.

References

1- Qing Zhang, Jie Gu, Shuo Wei, and Ming Qi. , "Differences in Dry Sliding Wear Behavior between Al–12Si–CuNiMg Alloy and Its Composite Reinforced with Al2O3 Fibers". Materials., 2019 Jun; 12(11): 1749.

2- Avinash Bhat and Ganesh Kakandikar. , "Manufacture of silicon carbide reinforced aluminium 6061 metal matrix composites for enhanced sliding wear properties" , Manufacturing Rev. 6, 24 (2019) , Published by EDP Sciences 2019.

3- Sheng fang Zhang, Qiang Hao, and Zhihua Sha, . "Simulation Study on the Influence Law of Two-body Wear in Sliding Guide Ways", ICMEAS 2018, IOP Conf. Series: Materials Science and Engineering 470 (2019).

4- A. Fathy, A. Abu-Oqail, A. Wagih. , "Improved mechanical and wear properties of hybrid Al-Al2O3/GNPs electroless coated Ni nanocomposite structure of the GNPs." , Ceramics International, Volume 44, Issue 18, 15 December 2018, Pages 22135-22145.

5- Teguh Triyono, and Eko Surojo, Febri Budi Darsonoa , "The Effect of Case Hardening Treatment on Aluminum 7074 toward Its Hardness and Tensile Strength", Cite as: AIP Conference Proceedings 1931, 030058 (2018); https://doi.org/10.1063/1.5024117 Published Online: 09 February 2018.

6- A. Shanmugasundaram, S. Arul, A. Sellamuthu, "Investigating the effect of WC on the hardness and wear behavior of surface modified AA 6063" , Materials today: proceedings 5, (2018), 6579–6587.

7- YuxinLi, PengfeiZhang, PeikangBai,. "Microstructure and properties of Ti/TiBCN coating on 7074 aluminum alloy by laser cladding" , Surface and Coatings Technology. , Volume 334, 25 January 2018, Pages 142-149.

8- Ajith Arul Daniela*, Sakthivel Murugesana, Manojkumara,. "Dry Sliding Wear Behaviour of Aluminium 5059/SiC/MoS2 Hybrid Metal Matrix Composites" , Materials Research. 2017; 20(6): 1697-1706 © 2017.

9- Mahesha N. S., Hanumantharaya R.*, Mahesh B. Davanageri,. "Tribological Wear Behavior of AISI 630 (17-4 PH) Stainless Steel Hardened by Precipitation Hardening", American Journal of Materials Science 2016, 6(4A): 6-14.

10- A.P.I. Popoola, O.S. Fatoba1, H.W. Nkosi1, V.S Aigbodion. Surface Hardening of Aluminum by Laser alloying with Molybdenum and Zirconium powder, Int. J. Electrochemist. Sci., Vol. 11, pages 126–139: 2016.