

TRIBOLOGICAL DEGRADATION FORECAST OF AL-BASED AUTOMOTIVE ALLOY UNDER DIFFERENT LEVELS OF USED MOTOR OIL

PROCENA TRIBOLOŠKE DEGRADACIJE AI LEGURE ZA AUTOMOBILE KOD RAZLIČITIH NIVOVA UPOTREBLJENOG MOTORNOG ULJA

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Keywords

- automotive Al-alloy
- wear
- friction
- used motor oil
- microstructure

Abstract

Tribological behaviour of Al-based automotive alloy is studied using pin-on-disc wear testing apparatus under different levels of used motor oil. Throughout the investigation, different pressures are applied but the sliding speed is constant. Experimental results prove that higher levels of used motor oil have a large negative influence on the tribological behaviour of the alloy. The oil acts as a lubricant by creating a thin film between the contacting surfaces which controls the wear characteristics. Application of long-used oils exhibits high wear rates with high friction coefficients due to quality loss in oil purity, viscosity, density, etc. Microscopical examination of the worn surfaces in a sliding environment of fresh oil reveals plastic deformation and microscuffing caused by oil film's resistance. In contrast, narrow grooves, random crevices and deep marks are formed under used oil for its harmful and corrosive nature along with increased surface contact.

INTRODUCTION

Cast Al-Si-Cu-Mg alloy is one of the important classes of material extensively used in the industry, especially in the automotive sector, for its lightweight and other excellent properties /1-4/. Cylinder blocks, cylinder heads, valve lifters, and pistons are the main automobile components. Cu and Mg are generally used to achieve higher performance through heat treatment, and their levels vary from 1.0 to 4.0 wt.% and 0.3 to 1.0 wt.%, respectively /5, 6/. Different alloying elements like Ni, Fe, Zn, Zr, Sc, etc. are also used to face a particular purpose /7-9/. The principal alloying element Si is added to the eutectic composition around 12.6 wt.% is the most favourable composition considering the overall properties. If the concentration of Si is below or above the eutectic composition, the resulting alloy is classified as hypo-eutectic or hyper-eutectic, respectively, /10, 11/.

As the alloys are more favourable for the automotive sector, the wear properties are a significant and common concern since the value of abnormal wear is very high. Wear essentially involves the removal of material that damages

Ključne reči

- Al legura za automobile
- trošenje
- trenje
- upotrebljeno motorno ulje
- mikrostruktura

Izvod

U radu se proučava tribološko ponašanje Al legura za automobile, korišćenjem Pin-on-Disk ispitivanja sa tribometrom u različitim uslovima kvaliteta motornog ulja. U istraživanju se koriste različiti pritisci sa konstantnom brzinom klizanja. Rezultati eksperimenata dokazuju da starije upotrebljeno motorno ulje ima veoma negativan uticaj na tribološko ponašanje legure. Ulje je mazivo koje formira tanak film između dodirnih površina, čime se postižu date karakteristike trošenja materijala. Primenom ulja koja su dugo u upotrebi javljaju se velike brzine trošenja materijala sa velikim koeficijentima trenja usled gubitka kvaliteta ulja: čistoće, viskoznosti, gustine, itd. Mikroskopska ispitivanja istrošene površine u uslovima klizanja sa svežim uljem pokazuju pojavu plastične deformacije i mikro brazdanja izazvanih otpornošću filma ulja. S druge strane, uski zarezi, proizvoljne šupljine i duboki tragovi se formiraju kod upotrebljenog ulja, zbog njegove štetne i korozivne prirode zajedno sa povećanim površinskog kontakta.

and distorts the movable contact surface /12/. Hence the low wear of the material provides better engine life. For that, motor oil is used to reduce friction and lubricate the engine's moving parts. Fresh motor oil must constantly pick up various metal particles and other compounds while running the engine. These penetrations including C, Zn, Pb, Ca, different metallic and non-metallic particles, burnt oil, and road dust are not easily separated from oil /13, 14/. During combustion, the engine produces various oxides of sulphur, nitrogen and carbon. Ultimately with water, they form different acids in the used oil. The quantity of these pollutants rises with the engine running time. The presence of these substances in lubricants has a very detrimental effect on automotive parts /15-17/. Motor oil needs to be continuously replaced after a certain period for better performance of the vehicle and environment. Otherwise, used oil can be cleaned or re-refined for reuse. As such, it is essential to identify the engine lubricants being used under different conditions to evaluate their performance and capacity. This safeguards the engine components and facilitates the creation of superior engine oil formulations or enhancement of existing ones.

It is well established that long-used oil harms engine materials and the environment /15, 18, 19/. However, it is yet to be known how long the oil has been used and the extent of this damage. Adequate tribological studies have not been performed on this type of alloy where long-used lubricants at different levels are considered. This investigation reports in detail the effect of different levels of used motor oil on the wear rate, friction coefficient, and surface morphology of the Al-based automotive alloy.

MATERIALS AND METHODS

The Al-12.7Si-2.1Cu-0.8Mg-0.3Ni-0.3Fe alloy of Al at the eutectic level is cast into a permanent mild steel mould of 20×200×300 mm³. A graphite made crucible is considered in a natural gas pit furnace where aluminium, copper, magnesium and highly pure Al-50%Si master alloy are used. Before pouring, the melt is strung at 700 °C, and the mould is preheated at 250 °C. An appropriate flux cover is used during the melting period to avoid oxidation. The chemical composition is explored by the spectrochemical method for the alloy.

The cast alloy is then thermally treated by homogenisation at 450 °C for 12 hours, solutionisation at 535 °C for 2 hours, and after that salt water quenched. Specimens of 14 mm length and 5 mm diameter are prepared by machining for wear study. To enhance the peak strength, the samples are aged for four hours at 200 °C /20, 21/. An electric muffle furnace capacity of 900 ± 3 °C is used for the heat treatment process. A pin-on-disc wear testing machine is employed to study the tribological behaviour of the alloy following ASTM Standard G99-05, /22/. During the tribological test, the surfaces of the sample are pushed against a stainless-steel rotating disc. During the wear test, a nominal load of 30 N, corresponding to a contact pressure of 1.53 MPa, is applied to the disc, while a range of 5 to 50 N loads are used for additional testing. The disc is allowed to rotate at 300 rpm with a 49 mm track diameter, resulting in a maintained 0.77 m/s sliding speed. The working environments in terms of temperature and humidity were 22 °C and 70%, respectively, during the conducted experiment. The surface hardness and roughness of the discs were approximately HRC 95 and 0.45 µm. Nine samples are considered for an individual test, and the average result is used to plot the graph. Drip-type single-point lubrication of five drops per minute between alloy sample and the SS counter plate contact interface is maintained throughout the test. The motor oil grade SAE 20W-50 is employed to wear tests under a lubricating environment. Oil of the same grade is considered, as different levels of used oil after a 2600 cc octane-driven vehicle runs for about 0, 2500, 5000, and 7500 km on a timeline of about six months and termed as Condition 1, 2, 3, and 4, respectively. To measure some properties of this oil, such as specific gravity at 60/60F, kinematic viscosity at 100 and 40 °C, viscosity index, and sulphur contents, is conducted at the University Petroleum Laboratory following the ASTM standard methods. For this study, the specific gravity is determined using a hydrometer, while a viscometer bath is utilised to determine the kinematic viscosity. The sulphur content is analysed through the use of an X-ray

analyser. To determine the specific wear rates (*S.W.R.*), measured weight loss (*W*), distance travelled (*S.D.*), and normal load (*L*) applied to the surface of the samples, are considered. The sliding distance is calculated using the rotational speed and the track diameter of the disc. The friction coefficient (μ) is obtained by normalising the readings of the load cell (*F*) and the applied normal load, *L*. The following general equations are employed to calculate the various wear parameters:

$$\Delta W = W_{\text{initial}} - W_{\text{final}}, \quad (1)$$

$$S.W.R. = \frac{\Delta W}{S.D. \times L}, \quad (2)$$

$$\mu = \frac{F}{L}. \quad (3)$$

A USB digital type microscope is employed for microstructural observations and a JEOL scanning electron microscope type JSM-5200 is used for SEM analyses of the alloy surfaces before and subsequent to wear. Roughness of the worn surfaces is measured by Tylor Hubson surface roughness tester. The pictures of the wear testing machine, wear specimen and counter body as the experimental setup are shown in Fig. 1.



Figure 1. Photo of wear testing machine setup.

RESULTS AND DISCUSSION

Motor oil properties

Table 1 provides the experimental characteristics of different grades of used motor oil. It points out that sulphur content and specific gravity increase with the level of usage, whereas all kinds of viscosity decrease. Fresh motor oil is always contaminated with working engine time. So various harmful foreign materials such as water, salt, dirt, metal scrapings luge, oil-soluble products and other materials, that accumulate gradually.

These are added to the weight, so the specific gravity of used oil is higher. The decline in the viscosity property may be due to the presence of solvents in the oil, but the primary reason is the high-temperature combustion process that can cause the oil molecules to shear and crack into smaller molecules, leading to a reduction in viscosity. Sulphur is emitted from the exhaust gases of the combustion engine, which is an indicator of poor oil quality and harmfulness. The rate of degradation is dependent on the level of oil used and is more significant for oil that has been used for an extended period /16, 23/.

Wear behaviour

The impact of varying levels of used motor oil on the wear rate of the alloy is illustrated in Fig. 2 at different sliding distances under applied pressure of 1.53 MPa and sliding velocity of 0.77 m/s. It can be concluded from the graphs that the trend of wear rate is similar in all motor oil environments. However, the intensity is higher as long as used motor oil is applied. In the early sliding stages, the wear rate increases to a certain point and then decreases due to uneven mating surfaces and surfaces becoming familiar, respectively. It is worth noting that the wear rate is extensively lowest, having the above trend under fresh motor oil. The decline in wear rate is due to the formation of a protective oil film between the contacting surfaces, which helps to prevent friction. The thin film created by engine oil is both efficient in facilitating movement and sufficiently viscous to minimise contact between moving surfaces. Engine oil also serves additional purposes such as heat transfer, protection against corrosive damage, sealing of potential cracks, and cleaning of residual deposits. Consequently, the wear rate decreases over extended sliding distances, /24, 25/.

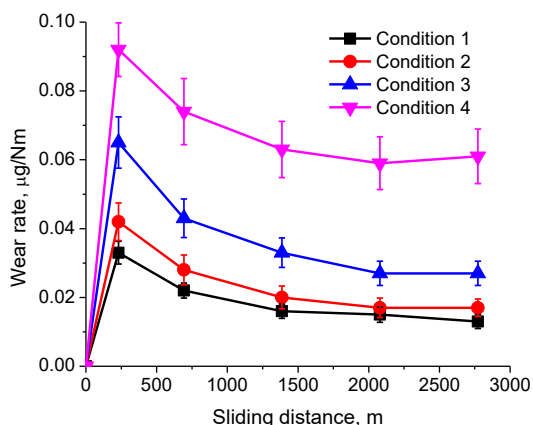


Figure 2. Changes of wear rate with sliding distance under motor oil.

Table 1. Several properties of different used motor oils.

SAE 20W-50	Specific gravity at 60/60°F	Viscosity at 100°C (cSt)	Viscosity at 40°C (cSt)	Viscosity index	Sulphur cont. (wt%)
Fresh motor oil	0.8899	19.38	168.59	132	0.03
Used oil 2500km	0.8910	18.52	158.74	130	0.17
Used oil 5000km	0.8924	17.92	145.48	127	0.41
Used oil 7500km	0.9241	16.06	128.48	122	0.99

Therefore, the levels of used oil are high, the friction behaviour is also higher. The data in Table 1 also confirm the state of affairs. One thing to note is that the friction trend under fresh oil conditions is downward. The trend goes upward when the used oils are applied, which is more

During engine operation, heavy metals and harmful chemical compounds accumulate in used engine lubricants. Burnt oil along with additive breakdown products and metal particles from engine wear, such as arsenic, nickel, lead, and cadmium, are the contaminants found in used oil. Many of these contaminants are extremely hazardous. Additionally, used lubricants contain numerous elements, including aluminium, iron, copper, magnesium, tin, and silicon. These particulates affect the rate of alloy wear. One observable fact is that wear increases significantly when long-used motor oil is considered. Higher levels of foreign particles, along with harmful chemical compounds, can potentially trigger a three-body abrasive wear mechanism that leads to increased wear rates by damaging the worn surface /26, 27/.

The change of friction coefficient under the above sliding condition of the alloy is plotted in Fig. 3. Initially, the coefficient of friction fluctuates with sliding distance due to mating surfaces being comparatively rougher. The coefficient of friction of the alloy when sliding with fresh motor oil is significantly lower in all conditions, than with used motor oil. Motor oil reduces friction and wear by creating a thin oil film between moving engine parts. In addition, it cleans metal debris, improves the sealing effect, and facilitates heat transfer. During service, used motor oil loses its original properties, namely corrosive properties, density, viscosity, total acid number, flash point, cloud point, etc., becoming increasingly inefficient. These destroyed properties are responsible for the higher coefficient of friction, as it is controlled by the lubricating film.

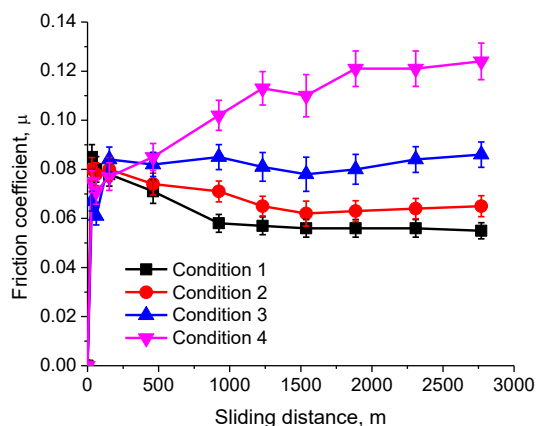


Figure 3. Friction coefficient fluctuations under different levels of used motor oil and the effect of sliding distance.

significant for long-used oil. It can be clarified that fresh oil can transfer heat and clean metal debris better than the used oil sequentially, /12, 26/.

Again, Fig. 4 displays the change of the coefficient of friction with the normal load under different levels of used

engine oil environment. The figure clearly illustrates the increased scenario of friction coefficient with load for all conditions. However, the increasing rate of these coefficients is low for fresh oil and proportionally higher for long-used oil. This occurrence can be endorsed by the increased amounts of worn-out particles from the counter body mixed with the engine oil continuously, which reduces the performance of the oil film between the tribo-pair. This tendency goes up as the used oil already contains several heavy particles and additional components from engine wear as well. In addition, increasing the pressure in the contact area causes the viscosity to increase exponentially as described by the pressure viscosity equation for the same oil and conditions /12, 28/. The quality of used engine oil has already been well clarified in the previous chapter by considering the information in Table 1.

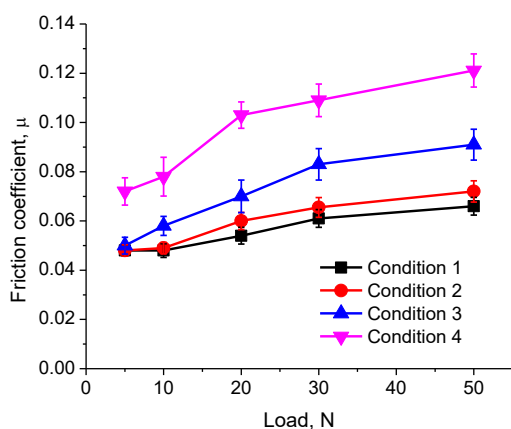


Figure 4. Friction coefficient fluctuations under different levels of used motor oil and the effect of applied load.

Optical micrographs

The optical images presented in Fig. 5, depict alloy surfaces before and subsequent to wear under different levels of used motor oil. Sliding distance of 2772 m, velocity of 0.77 m/s, and an applied pressure of 1.53 MPa are considered for worn surfaces of the wear study. Before wear on the highly polished surface, the alloy confirms the smoothness and absence of plastic deformation. A little scratch is created there owing to polishing. This kind of surface conveys more information with etchant than other common microstructures /29/. The α -Al phase with various intermetallic particles and eutectic Si scattered in intragranular- and grain boundaries form the common microstructures of Al-Si alloys. In this case, the microstructures only have different shades of lighter and darker tones that rely on how many different elements are in the alloys. Some needle-like shades are observed, which indicate the eutectic Si. The worn surface exhibits slight plastic deformation and micro-scuffing after wearing under fresh oil. It is because of the oil film formed between the tribo-pairs which provides lower wear and friction of the alloy. Worn surfaces after wearing under different levels of used motor oil show deep grooves and pitting from smooth surfaces to damaged surfaces, depending on the different levels of used motor oil. As too-long used motor oil is applied, the surface damages accelerate as the lower quality may have contributed to the discontinuous tribo-film. In particular, oil deterioration is associated with the genera-

tion of acids and metallic particles that cause engine wear. The metallic particulates accelerate wear, which in turn produces more contaminants. This process is identified as a chain reaction of wear, /24, 27/.

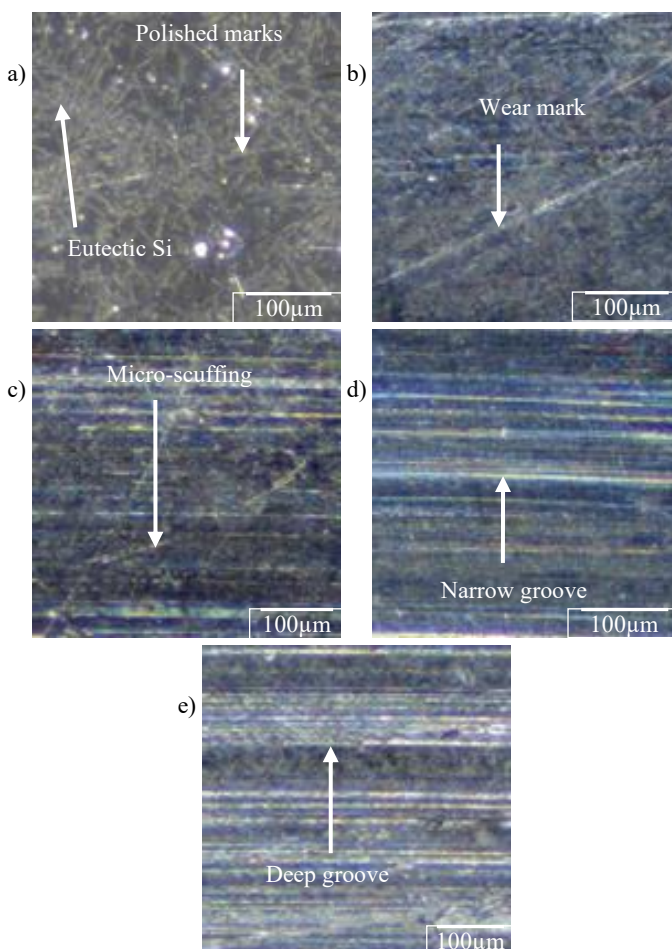


Figure 5. Optical worn surfaces of the alloy: a) before; after wear under used oil Conditions b) 1; c) 2; d) 3; and e) 4.

Roughness

A quantitative analysis of the surface roughness of worn surfaces of the alloy has been attempted and is graphically presented in Fig. 6. Adhering to upper worn surfaces, roughness increases with the degree of oil used. When higher label of used oil is considered, the roughness of the surfaces increases. It is greatly increasing beyond 5000 km used oil.

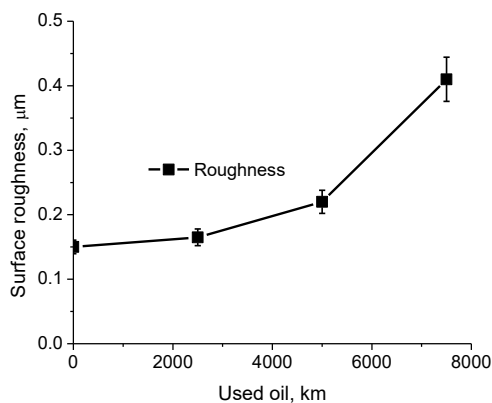


Figure 6. Surface roughness of the worn surfaces under different levels of used engine oil.

It has already been stated that fresh oil forms a thin film between the moving surfaces protecting them against heat and damage. Since the oil used continuously accumulates heavy metals and harmful chemical compounds, it can potentially trigger a three-body abrasive wear system that leads to an increase in surface roughness, /26, 30/.

Scanning electron microscopy (SEM)

SEM microphotographs of the alloy samples before and after wear are presented in Fig. 7, for the same condition under Sample 3 used motor oil environment. The worn surfaces clearly exhibit eutectic Si evenly distributed within the Al-matrix (Fig. 7a).

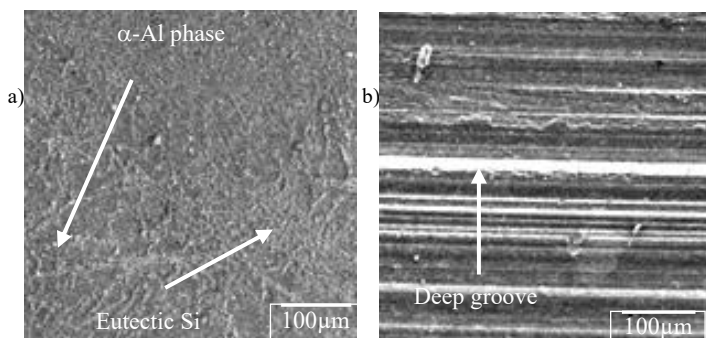


Figure 7. SEM images of the alloy worn surfaces: a) before wear; and b) after wear under used oil Condition 3.

After wear, the worn surface is impacted by abrasive wear, which reveals the scratches are most noticeable with random crevices and deep markings, scattered throughout (Fig. 7b). It is widely known as used engine oil holds various hazardous, highly toxic metal particles have an effect on the tribo-film. There is a tendency of third body wear, resulting in micro-cutting and ploughing. It also causes the friction force to oscillate. This results in a less uniform and smooth wear groove, /31, 32/.

CONCLUSIONS

The tribological study of Al-based automotive alloy yields the following conclusions.

Under a fresh motor oil sliding environment, the wear rate is low but increases gradually when applied with higher levels of used oil. Intended for used oil, the wear rate increases to some extent due to deterioration of oil quality through harmful foreign particles.

It maintains a relatively low wear rate, up to 2500 km of use. Beyond 5000 km, the wear rate increases exponentially, which may result in a mechanism of three-body abrasive wear and corrosive wear.

Fresh oil sliding conditions enable the motor oil to act as a lubrication film that keeps moving surfaces away from direct contact and offers a low friction coefficient. However, the lubrication quality, including viscosity, density, etc., degrades due to harmful foreign particles, generated acids, and engine temperature, eventually resulting in a higher coefficient of friction along with wear.

Under long-used motor oil sliding conditions, worn surfaces exhibit high abrasive wear and plastic deformation due to highly destructive oil properties that affect the tribo-film, resulting in more significant surface damage.

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REFERENCES

- Anderson, K., Weritz, J., Kaufman, J.G., Properties and Selection of Aluminum Alloys, Volume 2B. ASM Handbook, ASM Int. Materials Park, Ohio, USA, 2019. ISBN: 978-1-62708-208-2
- Song, H., Tian, Y., Liu, K., et al. (2025), *Study on microstructure evolution and heat treatment process of Al-Si-Cu-Mg cast alloys under two-step solution treatment*, JOM, 77: 1252-1266. doi: 10.1007/s11837-025-07156-x
- Kaiser, M.S., Khan, A.A., Sharma, S.D., Al Nur, M. (2023), *Investigation on electrochemical corrosion behavior of eutectic Al-Si automotive alloy under 0.2 M HCl, 0.2 M NaOH and 0.2 M NaCl environments*, J Chem. Technol. Metall. 58(5): 969-980. doi: 10.59957/jctm.v58i5.134
- Zafar, S., Ikram, N., Shaikh, M.A., Shoaib, K.A. (1990), *Microstructure studies in Al-6% Si-1.9% Cu-x% Mg alloys*, J Mater. Sci. 25: 2595-2597. doi: 10.1007/BF00638064
- Mohamed, A.M.A., Samuel, E., Zedan, Y., et al. (2022), *Intermetallics formation during solidification of Al-Si-Cu-Mg cast alloys*, Materials, 15 (4): 1-24. doi: 10.3390/ma15041335
- Kaiser, M.S. (2018), *Effect of solution treatment on age-hardening behavior of Al-12Si-1Mg-1Cu piston alloy with trace-Zr addition*, J Cast. Mater. Eng. 2(2): 30-37. doi: 10.7494/jcme.2018.2.2.30
- Cai, Q., Fang, C., Lordan, E., et al. (2023), *A novel Al-Si-Ni-Fe near-eutectic alloy for elevated temperature applications*, Scripta Materialia, 237: 115707. doi: 10.1016/j.scriptamat.2023.115707
- Kaiser, M.S., Sabbir, S.H., Soummo, M.R., et al. (2020), *Heat treatment effect on the physical and mechanical properties of Fe, Ni and Cr added hyper-eutectic Al-Si automotive alloy*, J Chem. Technol. Metall. 55(2): 409-416.
- Shaha, S.K., Czerwinski, F., Kasprzak, W., et al. (2015), *Improving high-temperature tensile and low-cycle fatigue behavior of Al-Si-Cu-Mg alloys through micro-additions of Ti, V, and Zr*, Metall. Mater. Trans. A: 46(7): 3063-3078. doi: 10.1007/s11661-015-2880-x
- Al Nur, M., Khan, A.A., Sharma, S.D., Kaiser, M.S. (2022), *Electrochemical corrosion performance of Si doped Al-based automotive alloy in 0.1 M NaCl solution*, J Electrochem. Sci. Eng., 12(3): 565-576. doi: 10.5599/jese.1373
- Sui, Y.D., Jiang, Y.H., Wang, Q.D. (2022), *Effect of solution treatment on microstructure and mechanical properties of as-cast Al-12Si-4Cu-2Ni-0.8Mg-0.2Gd alloy*, China Foundry 19: 238-244. doi: 10.1007/s41230-022-1076-4
- Totten, G.E., Friction, Lubrication and Wear Technology, ASM Handbook, Volume 18, ASM Int., Materials Park, Ohio, USA, 1992. doi: 10.31399/asm.hb.v18.9781627081924
- Ajuka, L.O., Ogedengbe, T.S., Adeyi, T., et al. (2023). *Wear characteristics, reduction techniques and its application in automotive parts - A review*, Cogent Eng. 10(1): 1-33. doi: 10.1080/23311916.2023.2170741
- Nagy, A.L., Knaup, J.C., Zsoldos, I. (2019), *Investigation of used engine oil lubricating performance through oil analysis and friction and wear measurements*, Acta Technica Jaurinensis, 12 (3): 237-251. doi: 10.14513/actatechjaur.v12.n3.495
- Round, G.A., (1925), *Foreign material in used oil: its effect on engine design*, SAE Technical Paper 250004, Warrendale, PA, US. doi: 10.4271/250004

16. Hameed, D.K. (2021), *Deterioration in physical engine oil properties after different trip length*, Kurdistan J Appl. Res. 6 (1): 13-20. doi: 10.24017/science.2021.1.2
17. Sejkorová, M., Hurtová, I., Jilek, P., et al. (2021), *Study of the effect of physicochemical degradation and contamination of motor oils on their lubricity*, Coatings, 11(1): 60. doi: 10.3390/coatings11010060
18. Hamawand, I., Yusaf, T., Rafat, S. (2013), *Recycling of waste engine oils using a new washing agent*, Energies 6(2): 1023-1049. doi: 10.3390/en6021023
19. Armioni, D.M., Rațiu, S.A., Benea, M.L., Puțan, V. (2024), *Overview on the environmental impact of used engine oil*, IOP J Phys.: Conf. Ser.: 2927: 012007. doi: 10.1088/1742-6596/2927/1/012007
20. Toschi, S. (2018), *Optimization of A354 Al-Si-Cu-Mg alloy heat treatment: effect on microstructure, hardness, and tensile properties of peak aged and overaged alloy*, Metals, 8(11): 961. doi: 10.3390/met8110961
21. Kaiser, M.S., Kurny, A.S.W. (2011), *Effect of scandium on the grain refining and ageing behaviour of cast Al-Si-Mg alloy*, Iran. J Mater. Sci. Eng. 8(4): 1-8.
22. Davis, J.R., Metals Handbook Desk Edition (2nd Ed.), ASM Int., Materials Park, Ohio, USA, 1998. ISBN: 978-0-87170-654-6
23. Qasim, M., Ansari, T.M, Hussain, M. (2016), *Physico-chemical characteristics of Pakistani used engine oils*, J Petrol. Technol. Altern. Fuels, 7(2): 13-17. doi: 10.5897/JPTAF2015.0121
24. Hsu, S.M., Munro, R., Shen, M.C. (2002), *Wear in boundary lubrication*, In: Proc. Inst. Mech. Eng. Part J: J Eng. Tribol. 216 (6): 427-441. doi: 10.1243/135065002762355
25. Rațiu, S.A., Alexa, V., Josan, A., et al. (2020), *Study of temperature dependent viscosity of different types of engine used oils*, J Phys.: Conf. Ser. 1426(1): 012001. doi: 10.1088/1742-6596/1426/1/012001
26. Syrmanova, K.K., Kovaleva, A.Y., Kaldybekova, Z.B., et al. (2017), *Chemistry and recycling technology of used motor oil*, Orient. J Chem. 33(6): 3195-3199. doi: 10.13005/ojc/330665
27. Stachowiak, G.W. (Ed.), *Wear - Materials, Mechanisms and Practice*, John Wiley & Sons Ltd., West Sussex, UK, 2005. ISBN 0-470-01628-0 (HB)
28. Fatehallah, H.S., Hammoudi, Z.S, Zidane, L.Y. (2020), *Study the effect of oil viscosity on friction coefficient at point contact elasto-hydrodynamic lubrication based on experimental analysis*, Diyala J Eng. Sci. 13(2): 17-21. doi: 10.24237/djes.2020.13 203
29. Kaiser, M.S., Qadir, M.R., Dutta, S. (2015), *Electrochemical corrosion performance of commercially used aluminium engine block and piston in 0.1M NaCl*, J Mech. Eng. 45(1): 48-52. doi: 10.3329/jme.v45i1.24384
30. Ghosh, A., Sadeghi, F. (2015), *A novel approach to model effects of surface roughness parameters on wear*, Wear, 338-339: 73-94. doi: 10.1016/j.wear.2015.04.022
31. Kaiser, M.S. (2019), *Corrosion behaviour of Al-12Si-1Mg automotive alloy in acidic, alkaline and salt media containing Zr traces*, J. Chem. Technol. Metall., 54(2): 423-430.
32. Rațiu, S., Josan, A., Alexa, V., et al. (2021), *Impact of contaminants on engine oil: a review*, IOP J Phys.: Conf. Ser. 1781: 012051. doi: 10.1088/1742-6596/1781/1/012051

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