Study the Wear Characteristics of 2024 Aluminium Alloy at Different Temperatures

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Abstract:
Aluminium alloys are frequently exposed to elevated temperatures when utilized in high-temperature components including cylinder heads, engine blocks, and pistons. These alloys are more prone to wear when paired with harder substrates and exposed to forces at higher temperatures. In this work, the impact of various temperatures on the wear properties of 2024 aluminum was examined, in dry conditions, using a high-temperature pin-on-disc tribometer machine that was made. Three distinct sliding distances—1570, 2356, and 3141 m—and different normal weights—10, 20, and 30 N—were used in the wear experiments, which were conducted at various temperatures ranging from 25 to 225 °C. The sliding speed was maintained constant during the experiments at 2.6 m/s. It was found that the wear rate increases with rising temperature while the sliding distance, load, and sliding speed remain constant. The findings also show that, at lower loads, the wear rate increases slightly as the temperature rises.
Keywords: 2024 Aluminium Alloy, Elevated Temperature, Microstructure, Pin on Disc, Specific wear rate, Wear Coefficient, Wear Rate
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1. Introduction

The relevance of aluminium alloys in the engineering materials industry may be attributed to a number of aspects, including their exceptional resistance to corrosion and their high strength to weight ratio [1], [2], [3]. The majority of engineering sectors, such as car and aerospace applications, are using them at the moment [4], [5], [6], in these sectors, it is common to encounter working circumstances that include friction and wear. As a result, the study of aluminium alloy's tribological behaviour is becoming more important.

Many researchers have studied the mechanisms of aluminium alloys [7], [8], [9], [10], [11], as sliding speed and load increased, the mechanisms of the wear changed from mixing/oxidation to delamination and subsequently to severe metal wear. The tribological components in the industry are necessarily subjected to high temperatures because of the heat produced. At room temperature, it is well known how aluminium alloys wear when they slide against another material in dry conditions. Although wear at high temperatures is a severe issue in many industrial applications, including engine blocks, cylinder heads, and pistons, where some of these components are frequently needed to operate at temperatures of about 200 ℃, their wear characteristics alter at higher temperatures[11]. Also, there are several engineering applications where high-temperature tribology (the study of friction, wear, as well as lubrication) is critical, including hot sheet metal forming, power generation, and aircraft [12]. Pauschitz et al. [13] showed that wearing circumstances, wearing material, and mating material all have a role in the development of glazing layer formation. Depending on these layers, the friction coefficient and wear rate may be determined. The wear behavior of alloys and composites at high temperatures has recently been the focus of research. As a result of high temperatures, the wear behavior of alloys as well as metals is affected by the conditions of use. In general, the friction coefficient drops as the load increases, and at higher temperatures, a harder mating surface produces a larger friction coefficient [14], [15]. Aluminium alloys are subjected to high temperatures in service. When paired to harder surfaces and exposed to high loads at higher temperatures, these alloys become sensitive to wear [16], [17]. Wear caused by oxidation and delamination is classed as mild wear, whereas wear caused by plastic extrusion and melting is regarded as severe wear. Additionally, Wilson and Alpas [8] argued that a critical interface temperature resulted in mild-to-severe wear. This mild-to-severe wear transition happens when the contact temperature exceeds a limit value (approximately 0.4 times the alloy's melting point). Subsequent studies widely recognized the mentioned wear processes and the mild-to-severe wear transition criteria [18], [20]. Therefore, the main aim of this study is to investigate the influence of high temperatures on the wear characteristics of Al2024. A high-temperature pin-on-disc tribometer machine was built and used in this work for this reason.

2. Experimental Procedure

Materials

The experiments were carried out on the Al2024 rod, with a 10 *mm* diameter and 30 *mm* length. The counterpart disc, with a 120 *mm* outside diameter and a 3 *mm* thickness, was manufactured using duplex stainless steel (AISI 2507). The disc and aluminum alloy rod were tested for hardness using a Vickers hardness testing apparatus. The provided hardness values are an average of five measurements. The hardness of the disc is 233 *HV*, which is higher than the hardness of Al2024 (140 *HV*). The physical properties of the two materials are shown in Table 1, while their chemical composition is presented in Table 2.

TABLE 1. physical properties of AL 2024 and AISI 2507 [20].

Materials	Tensile Strength (MPa)	Yield Stress (MPa)	Young's Modulus (GPa)	Shear Stress (MPa)	Shear Modulus (GPa)	Fatigue Strength (MPa)	Hardness (HV)	Melting point (°C)	Density (g/cm^3)

Al2024	469	324	73.1	283	28	138	140	502 – 638	2.78
AISI 2507	799	551	200	__	77	802	233	1350	7.8

Table 2. chemical composition of al2024 and aisi 2507. (from the chemical composition test)

	Cu %	Mg %	Fe %	Si%	Mn %	Cr%	Zr %	Ni %	Mo %	Co%	P%	S%	C%
Al2024	4.84	0.55	0.25	0.33	0.65	0.05	< 0.00	_	_	_	_	_	_
AISI 2507	0.065	_	_	0.363	1.6	23.46	_	5.16	2.93	0.133	0.0171	0.0049	0.065

Materials Characterization

The Al2024 rod was machined, using a lathe machine, to prepare the wear specimens according to the ASTM G99-95 standard. Fig. 1 shows a schematic of the pin wear sample. To eliminate scratches and machining marks, the samples were grinded and polished using 800, 1500, 2000, and 3000 grit abrasive sheets. For each condition, three wear tests were performed, and the results were averaged. A pin-on-disc tribometer was used for all of the experiments, which were conducted at elevated and room temperatures.

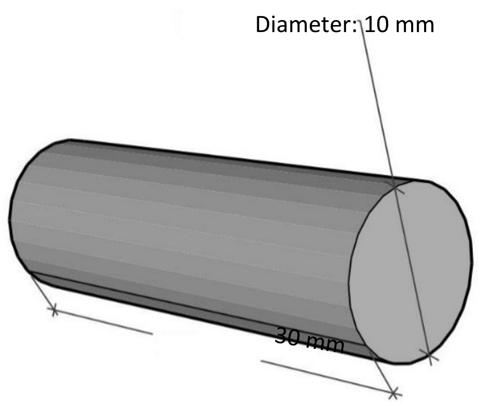
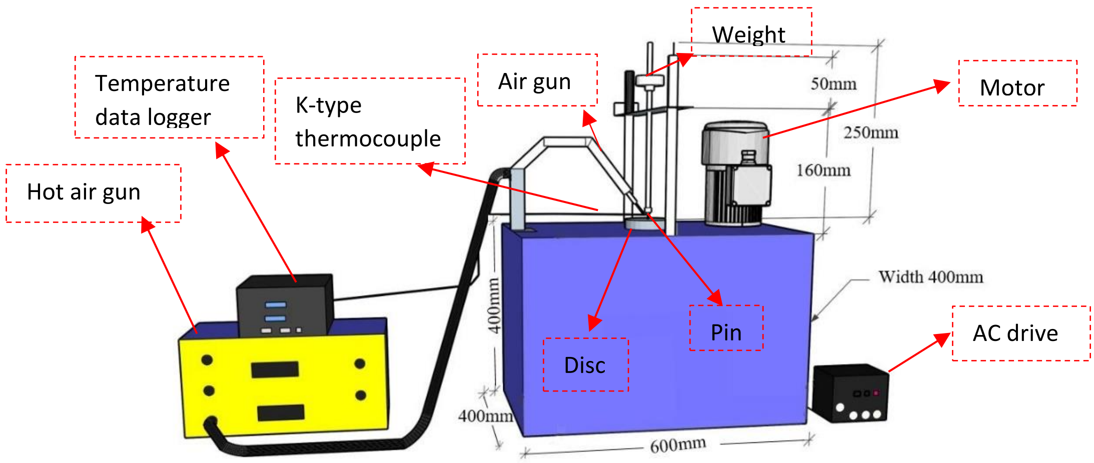


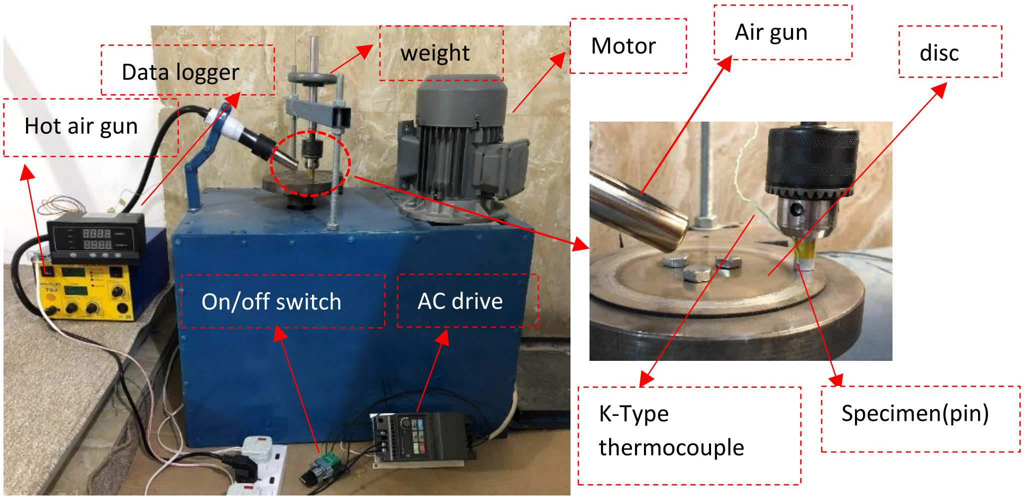
Fig. 1. A schematic of the pin specimen.

Pin on Disc Apparatus

A pin-on-disc tribometer with a high operating temperature was designed and manufactured to study the wear response of the Al2024 at elevated temperatures. The tribometer machine consists of a solid flange made from low carbon steel with a thickness of 20 *mm* and a diameter of 150 *mm*. The counterpart disc made from 2507 duplex stainless steel attached to the flange using three bolts. Both the flange and the counterpart disc are attached to a vertical shaft which is connected to a motor. The shaft rotates through a close-fit bush-bearing. To transfer rotation from the motor to the shaft, a compound V belt pulley was attached to the shaft below the flange and linked to the motor through a belt. The motor has a power of 0.75 *hp* and a maximum speed of 1365 *RPM*. There is a holder in which a cylindrical pin can be mounted on it. It is possible to change the sliding speed of the experiments in two different ways: either by adjusting the frictional radius or changing the speed at which the shaft is rotating. In this experimental study, the sliding speed is controlled by altering the motor's rotational speed while keeping the same frictional radius of exactly 50 *mm*. Motor speed can be varied according to the condition by the use of AC drive Type (Delta VFD EL-W), which is a device that controls the frequency of a motor which consists of the plug to turn on/off the device. There is also a controller to increase or decrease the RPM of the motor. To evaluate the wear of the samples at high temperatures, the temperature of the experiments was raised using a hot air gun. The gun produces a flow of hot air with a temperature range of 100 °C to 400 *°C*. During the wear test, a thermocouple (K-type) was attached to the specimen to detect the temperature of the contact surfaces around the area of contact between the pin and the counterpart disc. The temperature data was collected by using (KCM-TF) data logger that has two channels, and each channel can record temperature data with a sampling time of 1 *sec*. A schematic and a photograph of the high-temperature pin-on-disc tribometer device that was employed in this study are shown in Fig. 2.



(a)



(b)

Fig. 2. A schematic and photograph of test rig machine used in this study.

Wear Test

A pin-on-disc tribo-testing system was used to perform dry sliding wear tests at elevated temperatures. The pin of Al2024 was slid against a rotating 2507 duplex stainless steel disc at different temperatures such as (75, 125, 175, 225 *℃*, and room temperature). The wear tests were carried out with the three standard loads of (10, 20, and 30 *N*), and sliding distances of (1570, 2356, and 3141 *m*), at constant sliding speed of 2.6 *m/s*. The pins are thoroughly cleaned with acetone prior to and following the test, and then dried with hot air. The quantity of lost mass was then measured using an electronic balance with a resolution of 0.0001 *g*. Equation 1 was used to get the wear rate.

$$W_r = \frac{\Delta W}{\rho} \ (mm^3) \qquad (1)$$

Where (W_r) is the wear rate, (ρ) is the density of Al2024, and (ΔW) is the wear amount. The sliding distance was calculated using Equation 2.

$$S = 2\pi \times r \times RPM \times t \qquad (2)$$

Where (r) is the radius of the wear track, (S) is the sliding distance, (t) is the time, and (RPM) is the revolutions per minute.

Equation 3 was used to determine the specific wear rate:

$$W_s = \frac{V}{F * S} \ (\frac{mm^3}{N.m}) \qquad (3)$$

Where (W_s) is the specific wear rate, (F) is the normal load, (V) is the volume loss of material, and (S) is the sliding distance.

Every test was run three times to guarantee that the findings were accurate. As a result, the values obtained from these repeated tests were averaged, and those values were the ones that were considered.

Microstructure Test

An optical microscope type (carl zeiss axiovert 25) was used to inspect the worn surfaces of the pin in order to figure out the wear mechanism of the wear tracks. the microstructure inspections were conducted for all the experiments. to clarify the microstructure of the worn pin surface at different temperatures, the three temperatures, including 25, 125, and 225 ℃, were selected shown in figure 3. as for the rest of the temperatures used in this study, only the wear parameter values were mentioned.

3. Results and Discussion

Temperature Effect

Fig. 3 illustrates the impact of temperature on the rate of wear of Al2024. It can be seen clearly from the figure that the wear rate increases with increasing temperature. The amount of material removed significantly increases with the increase of test temperature at constant sliding speed, load, and sliding distance. These findings support the ideas of other researchers [24], [25], [26], who proposed that this behaviour may be explained by the fact that at elevated temperatures, the alloy in consideration gradually gets softer. Adhesive wear is caused by the friction between the soft pin surface and the hard spinning counterpart disc, which causes metal loss. It causes an increase in both the adhesion and transmission of the alloy to the steel counterface, which in turn leads to an increase in wear rate.

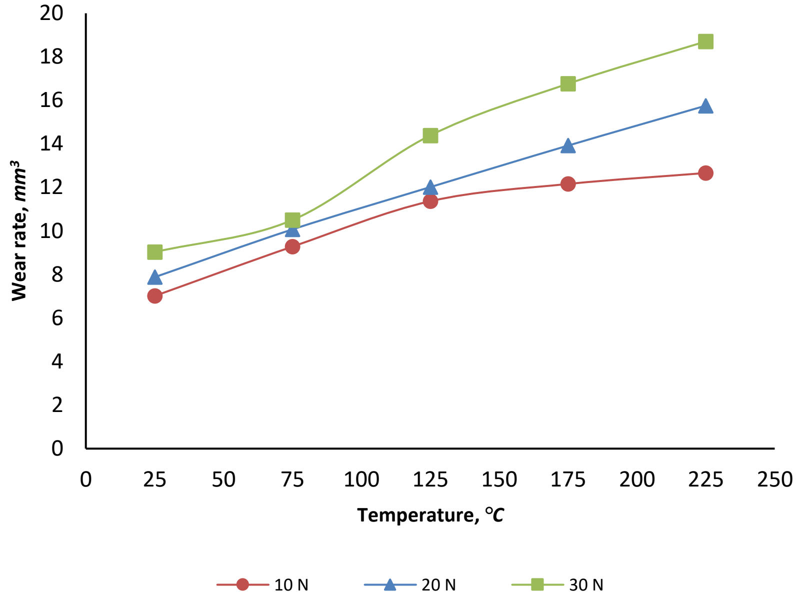


Fig. 3. Effect of temperatures on the wear rate at different loads

Effect of Load

Fig. 3 also depicts the effect of load on the rate of wear of Al2024. The results show that the load has a considerable effect on the wear rate, where the wear rate increases as the load increases for all the temperatures while the sliding speed and sliding distance are kept constant. This is because the amount of metal that is worn away and lost increases, these results support the ideas of Kumar et al. [21] as this is due to the increasing the asperity contacts between the aluminium alloy and counterface material and enhance the strength of the connection and contacts between them. At a constant sliding distance the specific wear rate decreases with increasing load, as mentioned in reference [22], it's likely because of the work hardening the alloy experienced, especially when subjected to higher loads (shown in Fig. 4).

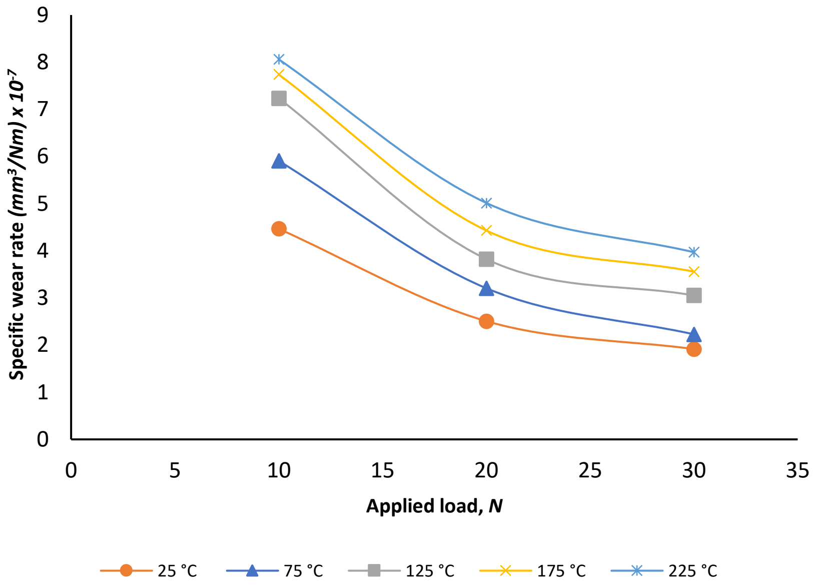


Fig. 4. Specific wear rate with applied loads at different temperatures

Sliding Distance Effect

The relation between sliding distance and wear rate at different temperatures is illustrated in Fig. 5. The tests were conducted at different temperatures (25, 75, 125, 175, and 225 *℃*) with a constant load of 20 *N* and a sliding speed of 2.6 *m/s*, throughout a range of sliding distances (1570, 2356, and 3141 *m*). An increase in sliding distance from 1570 *m* to 2356 *m* results in a considerable increase in the wear rate. Moreover, it was found that the alloy's wear rate increased significantly with an increase in the sliding distance at any temperature, and this increase in wear rate was associated with a rise in temperature. At a sliding distance of 3141 *m* and a temperature of 225 *℃*, the wear rate achieves its maximum value. At constant load, by increasing the sliding distance, the temperature rises gradually because of the enhanced contact and increased adiabatic heating. This outcome is in line with the findings of [27], [28], [29], and [30], which show that the wear rate rises as the sliding distance increases.

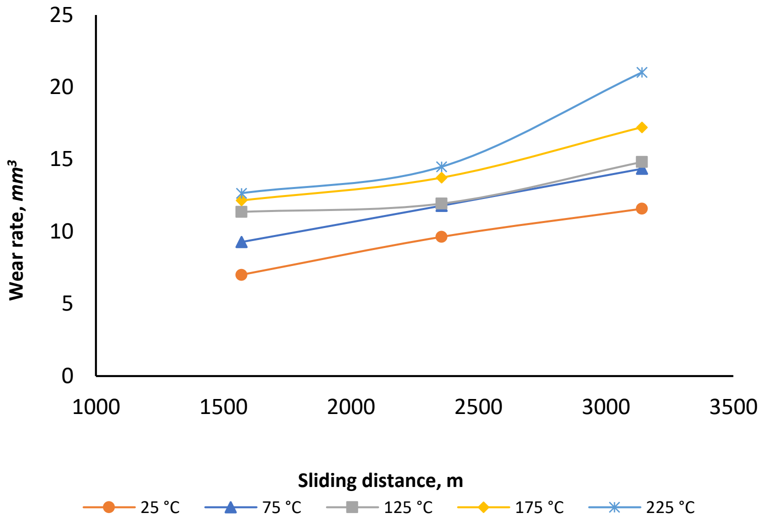


Fig. 5. Rate of wear versus sliding distance at various temperatures

Microstructure Examination

The macrostructures of the worn pin surface are shown in Fig. 6. The effects of loads and temperatures are clearly observed from the macrostructures. From the microscopic examination, it is apparent that wear tracks are predominantly abrasive in nature, with minor signs of adhesive wear. Furthermore, it is evident from Fig. 6 that the wear mechanism shifted from oxidation to delamination and finally to severe wear as load and temperature increased. This finding was also reported by other researchers [8], [9], [10], [11]. Sliding wear scars with both mild and severe wear were seen. Fine wear debris and scratches are result of mild wear behavior, but larger wear particles and coarse wear marks are result of severe wear.

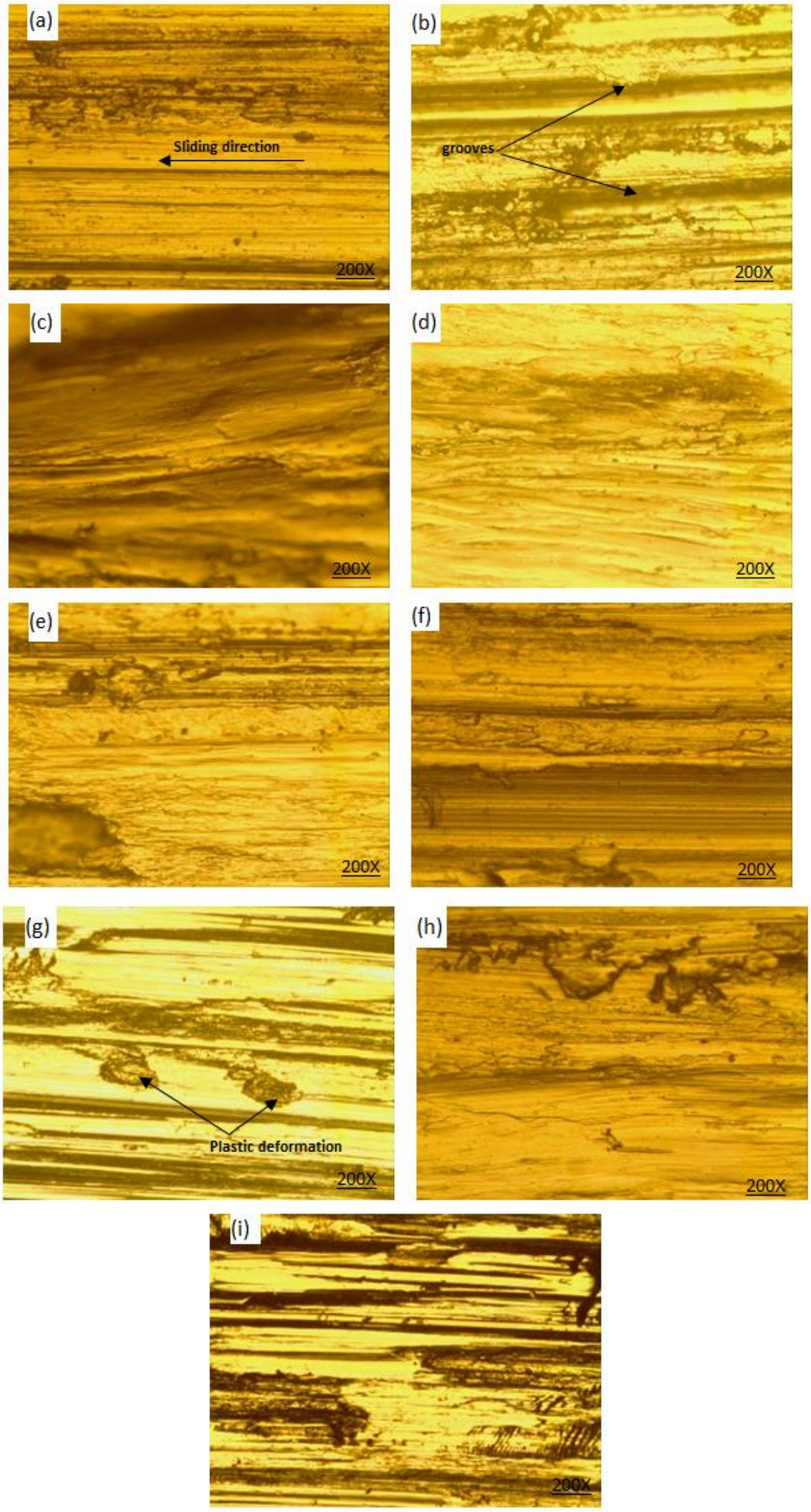


Fig. 6. Optical micrographs of worn pin surfaces of Al2024 at different loads and temperatures, a) 10 N, 25 °C, b) 10 N, 125 °C, c) 10 N, 225 °C, d) 20 N, 25 °C, e) 20 N, 125 °C, f) 10 N, 225 °C, g) 30 N, 25 °C, h) 30 N, 125 °C, and i) 30 N, 225 °C

4. Conclusion

The main goal of the current study was to determine the influence of varying temperatures, loads, and sliding distances on the wear behaviour of 2024 aluminium alloy. For this purpose, a high-temperature pin-on-disc testing apparatus was employed. The following points are the conclusions of this study:

1. It was found that the amount of material removal and wear debris significantly increases the wear rate with the increase of test temperature at constant sliding speed, load, and time, because at elevated temperatures these alloys are gradually gets softer.
2. It was clear that increasing load increases the rate of wear because the asperity contacts between the Al2024 alloy pin specimens and the counterface material increase as the load goes up.
3. As the temperature rises, the wear rate increases slowly at lower loads.
4. As the sliding distance increases, the wear rate increases.
5. The specific wear rate has a directly proportional relationship to temperatures and is inversely related to loads.

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