

Experimental Study of the Hygrothermal Effect on Wear Behavior of Composite Materials

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Abstract

The hygrothermal effect on the wear behavior of composite material (fiberglass and polyester resin vf=40%) was investigated experimentally in this work. The study includes manufacturing of test device (pin on disc) according to ASTM G 99. In order to study the hygrothermal effect on wear behavior of composite materials the hygrothermal chamber was manufactured. The experimental results show that the wear of glass fiber/polyester increased with increasing the load, sliding speed and sliding distance. The load and sliding distance were more effective on the wear of the composite rather than sliding speed. Also, it has been revealed that, the hygrothermal is considerable effect that, the wear rate of glass fiber/polyester without hygrothermal effect is lower than wear with hygrothermal effect. Applied load is the wear factor that has the highest physical influence on the wear of composites materials than other wear factors. Also, the wear of glass fiber/polyester without hygrothermal effect is lower than wear with hygrothermal effect.

Key Words: Hygrothermal, composite materials, pin on disc, Wear.

الخلاصة :-

تم دراسة تأثير الحرارة الرطبة على سلوك التآكل للمواد المركبة (الألياف الزجاجية والبولىستر الراتنج، كسر حجمي = 40%) تجريبيا في هذا العمل. وتشمل الدراسة تصنيع جهاز الاختبار (pin-on-disc) من أجل دراسة تأثير الحرارة الرطبة على سلوك التآكل للمواد المركبة تم تصنيع غرفة الحرارة الرطبة. وأظهرت النتائج التجريبية أن تآكل الألياف الزجاجية / البولىستر يزداد مع زيادة الحمل، سرعة الانزلاق ومسافة الانزلاق. وكان الحمل ومسافة الانزلاق أكثر فعالية على تآكل المواد المركبة مقارنة من سرعة انزلاق. وقد تم الكشف عن أن للحرارة الرطبة تأثير كبير أن معدل تآكل الألياف الزجاجية / البولىستر ويكون معدل تآكل الألياف الزجاجية والبولىستر بدون تأثير الحرارة الرطبة أقل من ذلك مع تأثير الحرارة الرطبة. الحمل هو عامل التآكل الذي لديه أعلى التأثير على تآكل المواد المركبة مقارنة بعوامل التآكل الأخرى. أيضا، تآكل الألياف الزجاجية / البولىستر دون تأثير الحرارة الرطبة أقل من التآكل مع تأثير الحرارة الرطبة.

الكلمات المفتاحية : الحرارة الرطبة، المواد المركبة، pin on disc، تآكل.

1. Introduction

Composite materials became widely used due to their superior properties, such as low density and cost. Numerous applications have been allocated for these materials of automotive and aerospace industries such as bushes, seals, gears, cams, shaft, etc. NSM. (El-Tayeb *et.al.*, 2005). The importance of the tribological properties convinced many researchers to study the wear behaviour and to improve the wear resistance of polymers and polymer composites NSM. (El-Tayeb and BF. Yousif ,2005). Surface temperature is an important parameter in studying tribological behaviour of polymeric composite (Bahadur and Zheng ,1990; Visconti *et.al.*, 2001) investigate the wear of glass woven composite materials, sliding under dry conditions against smooth steel counter face. The matrix consisted of three different types: epoxy resin, epoxy resin filled with powders of silica and epoxy resin filled with powders of tungsten carbide.(Tosun *et.al.*,2002), study experimentally the wear of a fiber glass composite with polyester for speeds of 500 and 710 rpm with different loads (500 and 1000 g) using block-on-disk tester. It was found that the wear resistance of the fiber composite specimens is much more than the plain polyester. The applied load on the specimens is more effective on the wear behavior of the specimens than the speed. (chand *et.al.*,2007),determined the abrasive wear at different percentages of bamboo weight powder filled polyester composites under the diferent mode.It was found that the weight loss depends on bamboo powder concentration. The sliding distance increases was decreasing the weight loss.

Maximum loss of weight sample occurred at 20 weight bamboo powder. (**Nuruzzaman, 2012**), investigated the variation of friction coefficient and wear rate with sliding speed experimentally. A stainless steel 304 (SS 304) pin was used and which slides on different types of composite and polymer materials. The used materials such as cloth reinforced ebonite (commercially known as gear fiber), glass fiber reinforced plastic (glass fiber), nylon and polytetrafluoroethylene (PTFE).

In this work, the hygrothermal effect on the wear behavior of fiberglass composite with $v_f=40\%$ polyester resin was investigated using a pin on disc device which was manufactured. Also, the hygrothermal chamber was manufactured.

2. Materials

The sample of wear test made from composite materials which are consisting of fiber and polyester will be manufactured. The procedure consists of the following steps:

- 1- Glass mold was used of 1 cm diameter and 7 cm length, which has an open end as shown in figure (1).
- 2- Arrangement the fiber glass in the mold in the homogenous form to cover most volume of sample as shown in figure (2).
- 3- Mixed the polyester with the hardener according to the standard ratio (100 part of acrylic resin mixed with (2-3) part of hardener) [8].
- 4- Adding the result mixture to the mold with (40%) volume fraction
- 5- The composite materials specimens will solidify after 24 hours and then removed from glass mold as shown in figure (3).
- 6- Finally, the wear test samples will be obtained by cutting the samples to 4 cm the length as shown in figure (4).



Figure (1) Glass Mold



Figure (2) Distribution of Fiber in the Mold



Figure (3) Composite Materials samples



Figure (4) Desired Samples

3. Wear Measurement Device

In order to measure the wear rate of composite materials, the (pin on disc) device was built according to ASTM G-99 standards (**Tosun et.al., 2002**). Figure (5)

shows a schematic diagram of pin on disc and figure (6) shows a photograph of pin on disc device.

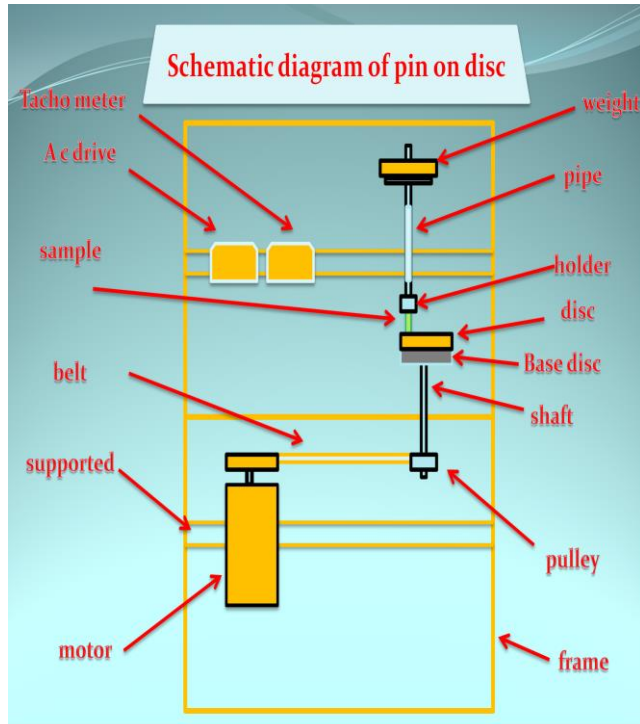


Figure (5) Schematic Diagram of Pin on Disc Device



Figure (6) Photograph of Pin on Disc Device

4. Wear Measurement Device Parts

The parts of for measurement wear rate device are: -

- 1-Motor drive, which rotate the disc so that the wear can happen, the gear motor was used, where it is three Phase induction motor having (1 hp), (220 v), (50 Hz) and 200rpm Capacity as shown in figure (7).
- 2-Two Pulleys and belt: which transmit motion from the motor drive to the shaft as shown in figure (8). The diameters of pulleys are (4cm) and (8cm). The pulley with (4cm) diameter was fixed on the shaft while the pulley with (8cm) diameter was fixed on the motor drive. The shaft speed rotation increased from 200rpm to 400rpm. The belt is 54 cm length, which was used to connect between pulleys.
- 3- Shaft, made of steel and of 35 cm length and 2.5 cm diameter, which was used to connect the small pulley and base disc and disc.
- 4- Base disc and disc, made of steel with a diameter of 10 cm and the thickness is 1 cm as shown in figure (9). The hardness of disc is 64HRC, which is measured by hardness test.
- 5- Holder. It used to fix the sample on rotation disc without any motion. It made of steel with length of (3.5cm) and inside diameter of (1cm), When the holes was drilled around the outer diameter of the holder to holding the sample by screw through the holes as shown in figure (9).



Figure (7) Motor Drive



Figure (8) Belt and Pulleys



Figure (9) Holder and Disc

- 6-Pipe and Shaft, which is used to fixed the holder. The pipe was made of steel with a length of (20cm) and a diameter of (1cm). To apply the load on the sample, the shaft was made of steel with 35cm a length and an outer diameter of (1cm) to connect the load through the pipe when it fixed the holder and sample.
- 7- Different weights were used to apply load on the sample, (10, 20 and 30N).
- 8- Tachometer, which is used to measure the speed of the engine shaft.
- 9-AC Drive, which is used to test the sample at different rotation speed of the disc by reducing both, the frequency and the volt input to motor.
10. Supported Frame, it used to fix the wear rate device with dimensions of (80×80×160cm). The frame is covered by an aluminum plate to reduce effect of environment.

5. Hygrothermal Chamber

To study the hygrothermal effect on composite materials, hygrothermal chamber was built. Figure (10) shows photograph of hygrothermal chamber and figure (11) shows schematic diagram of hygrothermal chamber. The hygrothermal chamber consists of the following parts:

- 1-Air blower: it is a mechanical device for moving air or other gases. It is a centrifugal fan which increases the speed of air stream by rotating impellers.
- 2-Heaters: It is a square duct ($20 \times 20 \text{ cm}^2$) and of 40cm length. It consists of five stages and the distance between each stage is (10cm). Each stage contains heater of 50cm length and 1cm diameter of (220v) volt and 500W power. The heater duct covered with insulation forms for the thermal insulation so that the heat is not leaked.
- 3-Humidity source: - it is used to study the effect of the humidity on the wear rate of the composite material, electric cup was utilized, where it is 300W electric heating pots which adopts tubal internal heating component. It is made of high quality stainless steel where 200V and 300W.
- 4-Ducts: The duct is consisted of three parts. Part one is square duct (15cm) length and ($20 \times 20 \text{ cm}^2$) where it is used to join the exit side of the centrifugal fan to inlet the square duct heaters. Part two is square duct heating (40cm) length and ($20 \times 20 \text{ cm}^2$) where it is used to join the exit of part one to inlet of the chamber. Part three is square duct (60 cm) length and ($10 \times 10 \text{ cm}^2$) where it is used to join the above of chamber to the above part one when it utilized to return air from the chamber to the part one of the ducts
- 5-Chamber, the dimension of the chamber is ($50 \text{ cm} \times 50 \text{ cm} \times 50 \text{ cm}$). This is a simulation chamber which is a cubic metal box made of iron. The entire chamber is covered with insulation forms. The first manhole is located in the middle of the right side of the chamber so that hot air from the two part of the duct will enter the chamber. The second manhole is located at the bottom of the right side of the chamber to inlet humidity air from the humidity source to the chamber. The third manhole is located at the top of the middle of the chamber for exiting the air from chamber to part one of the duct. The fourth manhole is located in the back of the chamber. It is used sensing the temperature and the humidity.
- 6-Control unit: - In this research, the control unit of temperature and humidity was manufactured. The control unit is shown in figure (12). It consists of (1) Digital indicating controller (temperature), (2) Digital indicating controller (humidity), (3) Temperature/Humidity transducer, (4) Power supply.

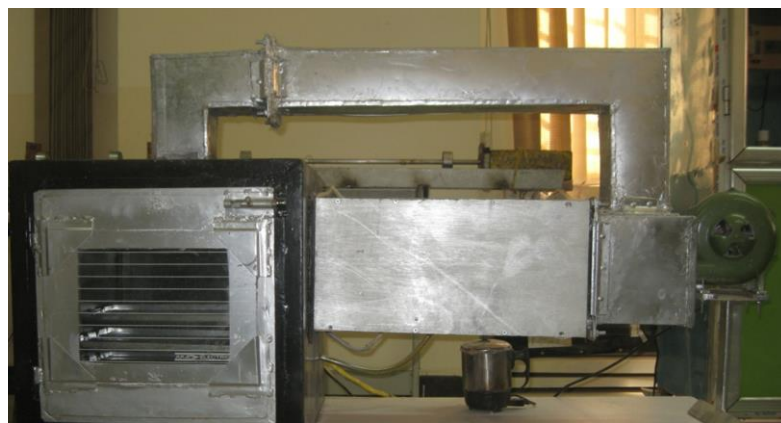


Figure (10) Photograph of Hygrothermal Chamber

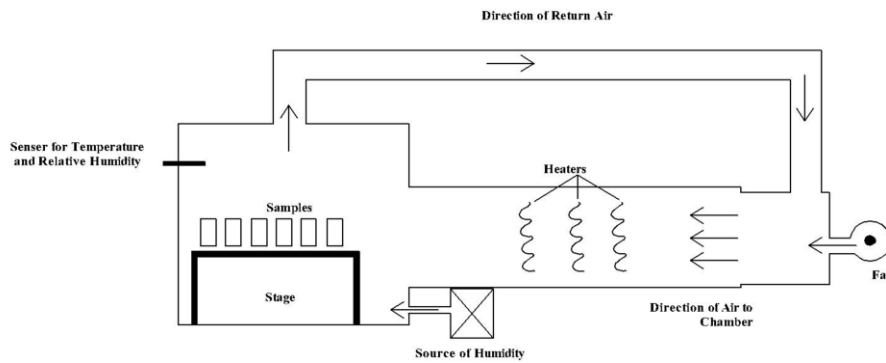


Figure (11) Schematic Diagram of Hygrothermal Chamber



Figure (12) Control Unit

6. Experimental Setup and Procedure

The experimental plan was formulated considering five parameters (variables). The five independent variables considered for this study, which is (load, sliding speed, sliding distance, temperature and humidity). The first three are process parameters, and the last two are a material dependent parameter. The levels of these variables chosen for experimentation are given in Table (1).

Table (1): Parameters of experimental work

Sliding speed, (RPM)	Load (N)	Sliding distance, (m)	Temp C ⁰	Humidity %
100	10	500	25	50
	20	1000	40	75
300	30	1500	60	95

The procedure of experimental work is divided into two manger stages. The first stage is applied hygrothermal effect on composite material samples using hygrothermal chamber. The second stage is measuring the wear.

In first stage: Samples are placed in the hygrothermal chamber and selected values of the temperature and the humidity, Initially the samples are placed in the

chamber and then it is weighted at different period of time to reach a stable state which is meant the weight does not increase.

In second stage: A pin-on-disc test apparatus was used to investigate the dry sliding wear characteristics of the composite depending on ASTM G99 standards. The wear specimen (pin) of 10 mm diameter and 40mm height was cut from as cast samples machined. The initial weight of the specimen was measured in a single pan electronic weighing machine with least count of 0.0001 g. During the test the pin was pressed against the counterpart rotating against steel disc with hardness of 65HRC by applying the load. After running through a fixed sliding distance, the specimens were removed, cleaned with acetone, dried and weighed to determine the weight loss due to wear. The difference in the weight measured before and after test gives the sliding wear of the composite specimen as shown in equation (1). The sliding wear of the composite was studied as a function of the sliding distance, the applied load, the sliding velocity, temperature and humidity.

$$\text{Wear} = \text{weight after a test} - \text{weight before a test} \quad \dots\dots\dots (1)$$

7. Results and Discussion

Figure (13) shows the relation between the wear of glass fiber/polyester with the humidity for different sliding distance of (500, 1000 and 1500 m) at load of 10N, speed of 100 rpm and temperature of 25°C. The profile of the curve shows that the wear is increased with increasing the humidity. Also, it is noticed that the wear is increased with increasing the sliding distance. This is because the increase in the sliding distance which led to an increase in temperature. Eventually, hardness is decreased and the wear rate will be increased.

Figures (14 and 15) are same as figure (13) but at temperature and load [(40°C, load=20N), (60°C, load=30N)] for figures (14 and 15) respectively. Same result will be found, wear is increased with increasing the humidity and it is increasing with increasing the sliding distance.

From figures (13, 14, and 15), it can be observed that the wear of glass fiber/polyester increases with increasing the load. This increase may be attributable to frictional heating. Also, it can be seen that, the wear of glass fiber/polyester increases with increasing the temperature.

Figures (16, 17, and 18) are same as figures (13, 14, and 15) but at sliding speed 300 r.p.m. Same result will be found as figures (13, 14, and 15).

From figure (13) to figure (18), it can be seen that the wear of glass fiber/polyester increases with increasing the load. This is because the increases of the temperature and load will cause an increase in the wear. Also, the increases of sliding speed causes increases in wear rate.

Figure (19) illustrates the relation between the wear of glass fiber/polyester with the temperature for different loads of (10, 20 and 30N) at sliding speed of 100 rpm, sliding distance of 500 m and humidity of 50%. It can be seen clearly that the wear is increasing with increasing the temperature. It might be expected that wear would increase as the temperature rise, because the hardness and yield strength was decreases. Also, it is noticed that the wear is increased with increasing the load due to the increases in temperature and fraction.

Figures (20) and (21) give the same relation as figure (19) for sliding distance (1000 and 1500 m) respectively. Similar results will be found as figure (20).

From figures (19, 20, and 21), it can be observed that the wear of glass fiber/polyester increases with increasing the sliding distance. This increase is due to increases in time of frictional contact. Also, the wear of glass fiber/polyester is very affected by increases temperature and load.

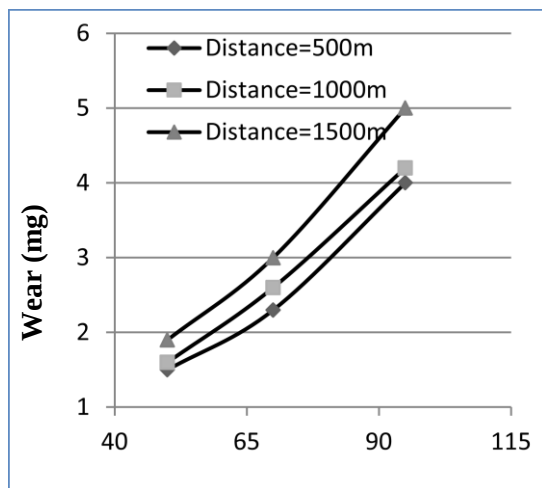
Figures (22, 23, and 24) are same as figures (19, 20, and 21) but at humidity 95%. Same result will be found as figures (19, 20, and 21).

From figure (19) to figure (24), it can be seen that the wear of glass fiber/polyester increases with increasing the humidity, temperature and load. The load and sliding distance were more effective on the wear of the composite rather than sliding speed. The load has the highest physical influence on the wear of composites materials than other factors.

Also, the increases of sliding speed causes increases in wear rate.

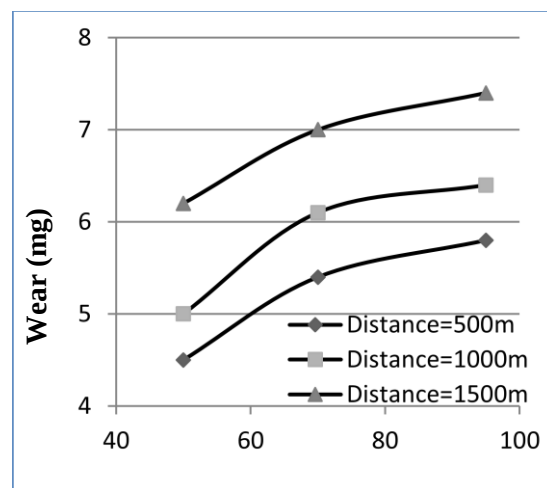
8. Conclusion

- 1- The wear of glass fiber/polyester increased with increasing the load, sliding speed and sliding distance.
- 2- The results note the hygrothermal is considerable effect that, the wear of glass fiber/polyester without hygrothermal effect is lower than wear with hygrothermal effect.
- 3- The effect of temperature is more pronounced on wear of glass fiber/polyester rather than humidity.
4. The load and sliding distance were more effective on the wear of the composite rather than sliding speed.
- 5- Applied load is the wear factor that has the highest physical influence on the wear of composites materials than other factors.



Humidity(%)

Figure (13) Wear rate at temp=25°C,
load=10N , speed=100 rpm



Humidity(%)

Figure (14) Wear rate at temp=40°C,
load=20N , speed=100 rpm

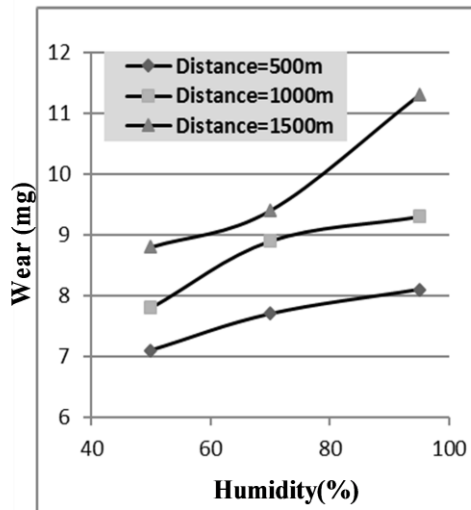


Figure (15) Wear rate at temp=60°C, load=30N , speed=100 rpm

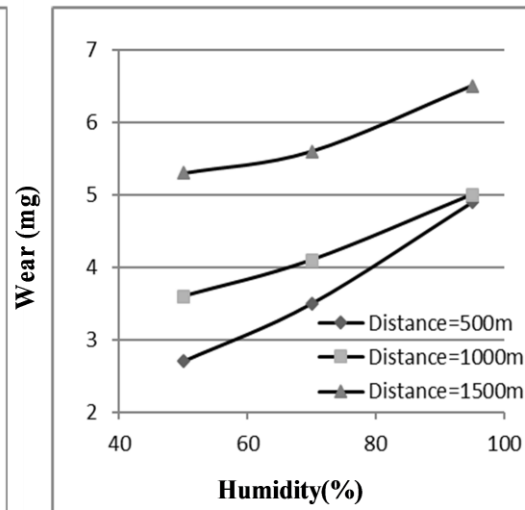


Figure (16) Wear rate at temp=25°C, load=10N , speed=300 rpm

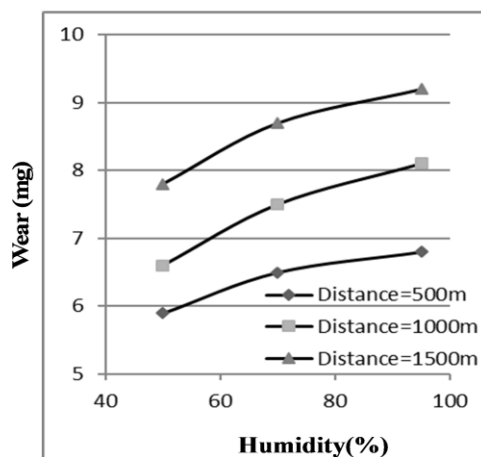


Figure (17) Wear rate at temp=40°C, load=20N , speed=300 rpm

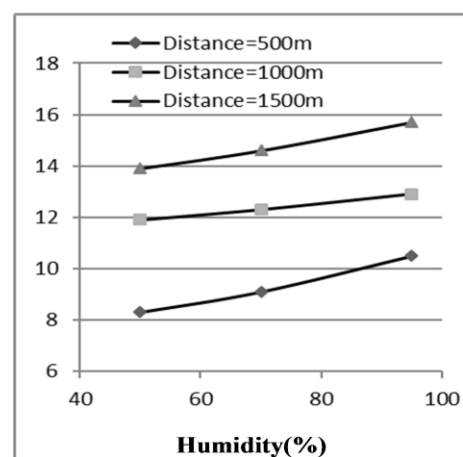


Figure (18) Wear rate at temp=60°C, load=30N , speed=300 rpm

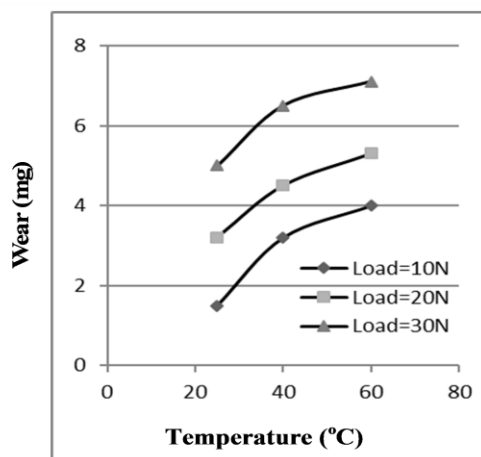


Figure (19) Wear rate at humidity 50%, speed=100 rpm, distance=500m

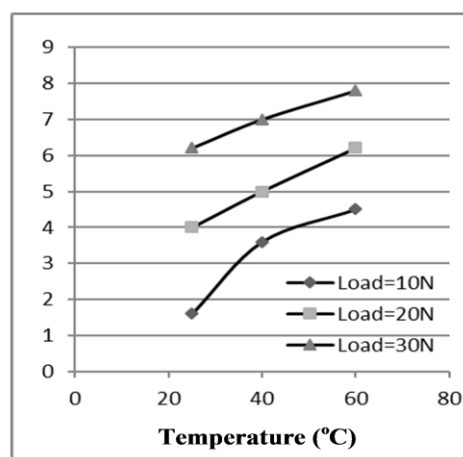


Figure (20) Wear rate at humidity 50%, speed=100 rpm, distance=1000m

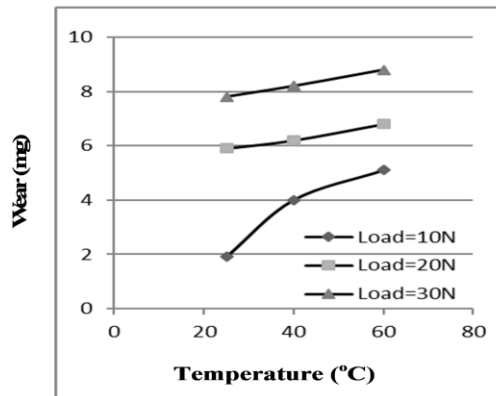


Figure (21) Wear rate at humidity 50%, speed=100 rpm, distance=1500m

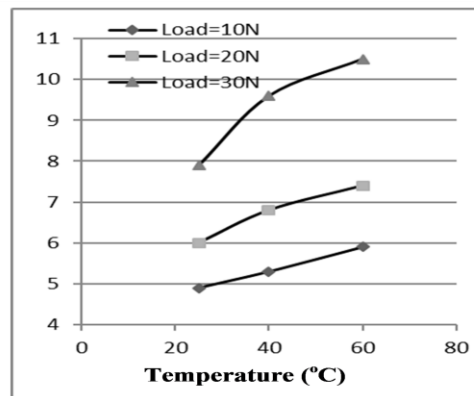


Figure (22) Wear rate at humidity 95%, speed=300 rpm, distance=500m

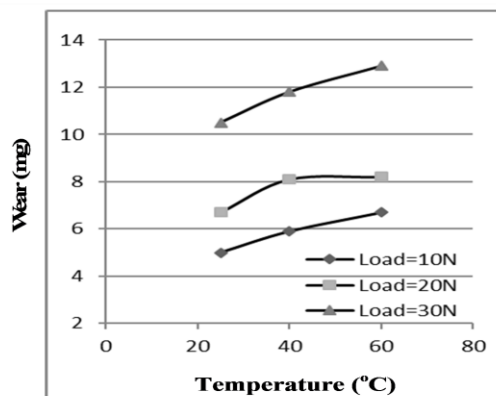


Figure (23) Wear rate at humidity 95%, speed=300 rpm, distance=1000m

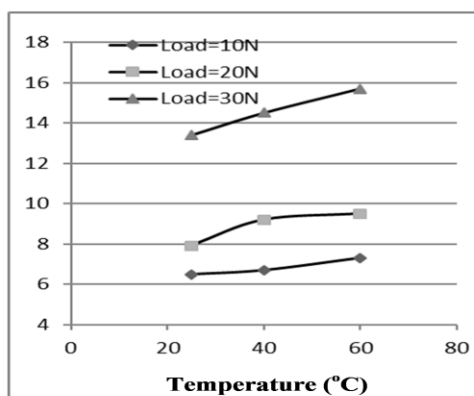


Figure (24) Wear rate at humidity 95%, speed=300 rpm, distance=1500m

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