



Experimental Study on Tribological Characteristics of Steel Alloys for CNC Bending Machine

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Abstract

In this paper, the contact phenomenon of meshing of sliding gear tooth used in planetary gear train (PGT) of CNC bending machine is simulated to estimate the coefficient of friction (COF), frictional force (FF) and wear rate of various steel alloys. Planetary gear systems continually transmit highest torque and reduction ratio. In this work, the experiments are performed on a pin-on-disk apparatus to estimate tribological characteristics of different gear materials with different loading conditions. Pins were mounted in a pin holder and fed against a rotating disk at a required speed. The trials were performed on a group of steels alloys for duration of 5 min for load of 50 N and 100 N with disk speed of 350 rpm. The results show that the COF varies with duration of rubbing and normal load. In general, COF increases for a certain duration of rubbing and after that it remains constant for the rest of the experimental time. The wear of carbon steel is significantly reduced due to more carbon content. Hence, it becomes imperative to analyze the wear characteristics of different types of steel materials, particularly EN8, 20MnCr5, EN19, EN24 and M.S. sliding against EN-31 disk on a case-to-case basis in order to arrive at a more realistic assessment of friction and wear performance.

Keywords Pin-on-disk machine · Friction and wear · Material properties · Gear steels

1 Introduction

In much precision power-transmitting elements, the planetary gears are required such as in tractors, automobiles, aircraft engines, CNC bending machines and helicopters, where high torque-to-weight ratio is required. It is also used in the applications where high reliability and high efficiency are required. Nowadays, a critical need exists to develop new harder, tougher, lighter, more wear-resistant, oxidation-resistant and heat-resistant components which can operate effectively under high temperature and hostile environments. It mainly focuses on tribological analysis, which includes friction and wear for maximizing power output by reducing the frictional losses. Due to friction, the planetary gear system parts are prone to wear and fail during its normal working cycle by repetitive load during operation time. The main factors which are need to be considering while selecting

material depend upon the service factor and strength like bending strength and wear strength. Hence, in this paper experiments are proposed to conduct on a pin-on-disk apparatus for different types of pin materials of gears with the objective to study the tribological behavior and performance of gear steels.

In the machine-driven transmission, such as sliding or rolling friction pair under sporadic load as in gears and bearings is the key part in a machine. Gear transmission is extensively used in which the gears play a main role. Therefore, the life span of a gear determines the efficiency of machine-driven transmission [1]. When the gear friction pair slides or rolls under the contacting condition, it has a sliding speed, which causes and transmits alternating load. The load under sliding and rolling is a complicated process influenced by tribological load set and material properties, falling into the category of “the science of wear fatigue damage and inefficiency of loaded wear pair system in the machines and equipment” [2]. Extensive work has been carried out on the friction and wear reduction in gears. The present work is based on studies performed and presented by various researchers on reduction of friction and wear in planetary gears. To study and reduce the friction as well

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as wear, several techniques have been proposed in recent years and discussed in this section. The various papers are referred in literature review to identify further scope to simulate tribological behavior in planetary gear drive. Godase et al. [3] studied the COF and wear rate of different steels alloys and perceived that rubbing changes the coefficient of friction. Initially COF increases with rubbing, and after particular time it remains constant. With the increase in normal load, COF also increases except SS202. With the increase in carbon content, strength of material also increases. Charoo et al. [4] studied the effect of friction and wear on EN8 and EN24 under lubricated condition where COF decreases with the increase in speed and load and increases with the increase in temperature. The COF of EN8 is lower than that of EN24, whereas wear of EN8 is higher than that of EN24. Sekunowo et al. [5] studied wear characteristics of carburized mild steel which involved pack carburization of specially prepared mild steel specimens under a finely pulverized charcoal environment at 750 °C, 800 °C, 850 °C, 900 °C and 950 °C with tempering at 500 °C for 30 min. Deore et al. [6] estimated wear rate, FF and COF of SS316, SS304, SS410, copper, aluminum and brass. Aluminum has highest COF, while brass shows lowest among the specimens. Ming et al. [7] conducted experiment on 20CrMnTi material on M2000 friction and abrasion tester under dry condition and lubrication in the coupling of sliding and rolling. 20CrMnTi gear steel is mainly having abrasive wear, adhesive wear and oxidation wear under the dry condition. There is mainly surface fatigue wear of 20CrMnTi under the lubricated condition. Li et al. [8] compared the tribological behavior of sintered gear materials with standard gear materials. The result shows that for the pairs of same gear materials 16MnCr5 has a lower COF. Also at higher as well as lower speeds, the wear resistance of 16MnCr5 pins is always better. Sardar et al. [9] evaluated the wear behavior of a nonmetallic spur gear in which the nonmetallic gears are used instead of a metallic gears because of its fatigue and wear characteristics. It is observed that when the cement filler loading increases, the adhesive wear rate reduced significantly as hardness and toughness of the material improves due to strengthening. Kurokawa et al. [10] investigated the tribological properties of polyoxymethylene composites with silicon carbide and polytetrafluoromethylene where the COF decreased drastically due to the lubricant. Also the performance of these gears was confirmed to be satisfactory due to noiseless operation during the dry condition, whereas Li et al. [11] compared friction and wear of two sintered gear materials with the standard gear materials. Ghazali et al. [12] investigated the wear characteristic of biopolymer in which injection molding is used for manufacturing of spur gears. The tooth deformation, fracture and weight loss are

the wear formations which were revealed on biopolymer spur gear. Krantz et al. [13] analyzed the impact of oil consistency and added substances in the normal wear rate of spur gears. The information likewise demonstrates an exponential pattern between the normal wear rates and the surface weakness lives.

Breeds et al. [14] portray the plan and activity of a novel test fix for estimating the wear behavior of polymer outfits, whereas Mao et al. [15] examined the friction and wear characteristics of polymer in which tests were performed utilizing acetal pinions with acetal riggings and nylon pinions with nylon gears, with advance examination conveyed out utilizing disparate polymer gears. It was discovered that the surface temperature was the overwhelming element impacting the wear rate, and an underlying connection between gear surface temperature and apparatus stack limit has been set up and additionally created. Li et al. [16] examined the divergent polymer gear contact, rubbing and wear conduct to comprehend the behavior to explore the gear mechanism. To enhance the high grinding and wear of the rigging tip, a micron geometry change strategy, tip alleviation, has been utilized and critical frictional contact compel diminishment has been accomplished. Mao et al. [17] investigated the reduction in the fatigue wear of gears through micro-geometry modification method using high precision of the rigging geometry, the tooth profile created numerically utilizing Python content interfacing with the finite element analysis (FEA) programming. Abdo et al. [18] studied the variations in friction of metals due to the effect of amplitude and frequency of vibration. Normal load and surface roughness are some of the factors that affect COF which results in undesirable vibration. It makes the use of response surface methodology for obtaining friction function model. Seidel et al. [19] investigated the potential of chemical alterations to study the influence the tribological properties of machined surfaces by the metalworking fluid additives. Hohn et al. [20] aged five mineral oil-based lubricants of gear at two different temperatures to analyze the changes in additive concentration, total acid number, viscosity and particle content to investigate the influence of two different stages of oil degradation and new oil on scuffing, gear wear pitting and micro-pitting. Micro-pitting performance decreases with light aging and increases with severe aging. Schultheiss et al. [21] analyzed the impact of the working conditions and the oil synthesis on the grease supply component and wear conduct was explored utilizing case-carburized for gears having small module. The examinations demonstrate that the rotational speed significantly affects adapt wear conduct. Expanding rotational speed does not essentially prompt more positive wear conduct of oil greased up gears. Moreover, the oil synthesis was appeared to influence wear conduct. Wright et al. [22] compared injection-molded composite gears that used fiber-reinforced thermoplastics with those made from

unreinforced polymers. A new method of characterizing the wear of gears is established that relates gear tooth wear and actual contact conditions.

Gears are essential parts of many precision power- and torque-transmitting machine such as an automobile. The major function of a gearbox is to transform speed and torque in a given ratio and to change the axis of rotation. Planetary gear systems are typically used to perform speed reduction due to several advantages over conventional parallel shaft gear systems [23]. Despite their advantages, the friction and wear produce in planetary gear is a major concern. Meshing of gears in the planetary gear set that forms the ratio changing mechanism of an automatic transmission produces friction in the gears. Many studies have examined the friction and wear caused by the meshing of sliding surfaces [1], but no one tried to simulate tribological behavior of meshing of sliding tooth. Hence, in this work the tests are proposed to conduct to investigate the friction and wear properties in dry and wet conditions (lubricant—SAE 20W40) of different steel alloys used in PGT on a reciprocating friction test rig using pin-on-disk configuration under various operating parameters such as speed and load.

2 Forces on Contacting Gears

A planetary gear train shown in Fig. 1a comprises one or more gears called as the planet and sun gears. In all the industrial areas, these gears play a vital role. Figure 1b shows force acting on a spur gear tooth and its components as normal force (F_n) which is resolved into two components, tangential (F_t) and radial component (F_r) with pressure angle (ϕ). Although there are many different failure modes in gears, the wear in gears is a major challenge to the designer.

Hence, the wear resistance is a key factor which is to be considered for selecting the material of gear for any application.

3 Experimental Methodology

3.1 Test Method

Standard test method is carried out on a pin-on-disk apparatus for wear testing. The wear rate in various systems will be relied upon the conditions such as the applied load, speed, the environment, sliding distance and the material characteristics. The amount of any wear test method lies in presuming the relative ranking of material combinations, because the pin-on-disk test method will not attempt to duplicate all the conditions that may be experienced in service, for example, lubrication, load, pressure, contact geometry, removal of wear debris and presence of corrosive environment.

3.2 Disk

The minimum speed of disk is 200 rpm, and maximum speed is 1800 rpm. The material used for disk is EN-31 hardened to 60 HRC and 1.6 Ra (surface roughness). The diameter of disk is about 30–100 mm. The thickness is in between 2 and 10 mm. The diameter of wear track is varied between 50 and 100 mm.

3.3 Sample Preparation

Pins are manufactured as per the gear steels which are suitable for planetary gear trains. The pins are machined with diameter 10 mm and 25 mm length. The pin is clamped in a jaw. The gear steels to be tested should fulfill the norms of G

Fig. 1 a Basic layout of planetary gears, b forces acting on contacting gears

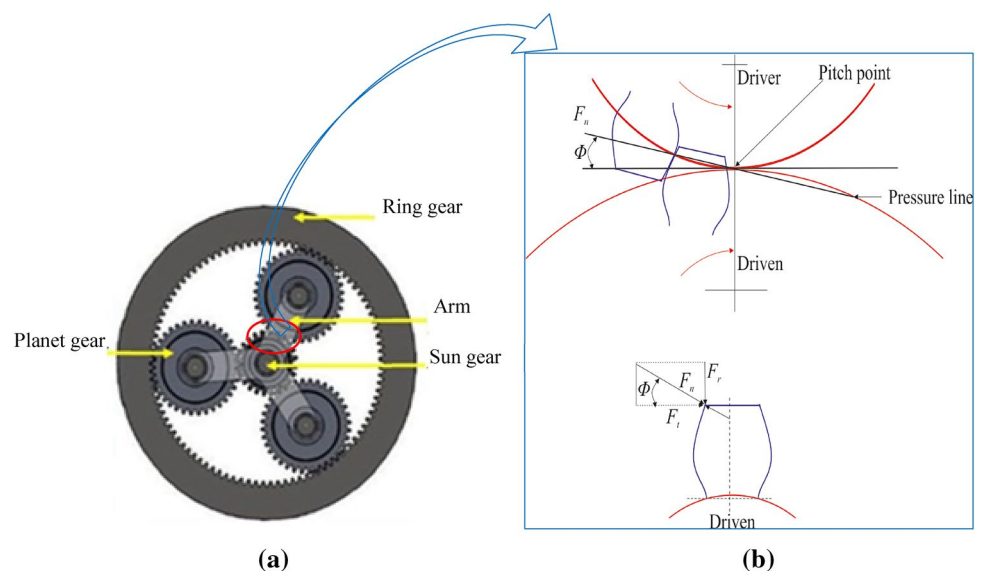
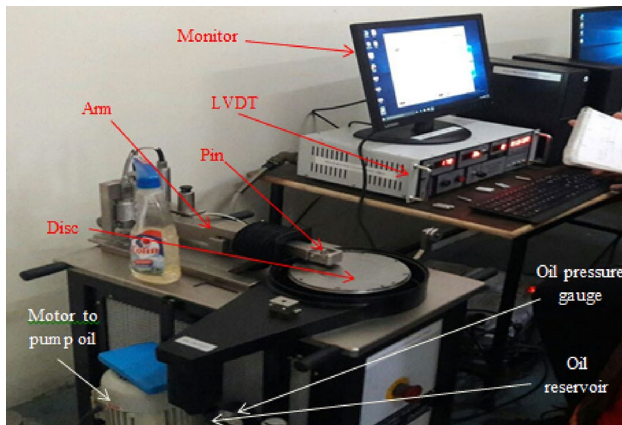


Table 1 Chemical composition of materials

Material	C%	Mn%	Si%	S%	P%	Cr%	Ni%	Mo%
EN8	0.39	0.74	0.17	0.017	0.012	–	–	–
20MnCr5	0.21	1.24	0.20	0.017	0.012	1.12	–	–
EN19	0.38	0.83	0.21	0.018	0.011	1.17	–	0.24
EN24	0.41	0.57	0.19	0.020	0.013	1.23	1.52	0.25
M.S.	0.20	0.96	0.17	0.15	0.011	–	–	–

**Fig. 2** Experimental setup

99. These norms are like dimensions, surface finish, material type, composition, processing treatments.

3.4 Chemical Composition of Materials

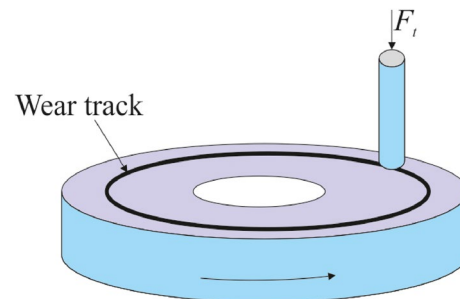
In *Metasys Testing and Calibration Laboratories* located in MIDC, Bhosari, Pune, India, all gear steels are tested for their chemical composition (Table 1).

3.5 Load

Various tests are carried out for a load varying from 50 to 100 N at 350 rpm. The different loads and the speed are selected as per the designed calculation of gears (Fig. 1) of CNC pipe bending machine [23]. At different loads and speed variation of wear, frictional force and COF with duration of rubbing are compared and investigated.

3.6 Experimental Set Up

Figure 2 shows the experimental setup of pin-on-disk apparatus. The main component of pin-on-disk apparatus is pin and rotating disk. The pin-on-disk is equipped with load cell and LVDT to measure the frictional force and vertical displacement of pin. The disk is rotated by motor at different speeds in such a way that vibration does not

**Fig. 3** Schematic diagram of pin-on-disk apparatus

affect the test. The specimen holder is attached to the lever arm which has pivot. The pin specimens to be tested are of cylindrical shape. The material for the disk is EN-31, and the pin is fed against the rotating disk by applying deadweight load on pin due to which the wear of pin takes place. Machine is equipped with a controller, data acquisition system and WINDUCOM 2010 software to obtain the required results. Tribological characteristics are determined on pin-on-disk apparatus for different gear materials and loading conditions. The friction force induced in between pin and disk. And this friction force is sensed by load cell.

The minimum speed of disk is 200 rpm, and maximum speed is 1800 rpm. The material used for disk is EN-31 hardened to 60 HRC and 1.6 Ra (surface roughness). The diameter of disk is about 30–100 mm. The thickness is in between 2 and 10 mm. The diameter of wear track is varied between 50 and 100 mm. Various tests are conducted in a load ranging from 50 to 100 N. At various loads and sliding velocities, tribological behavior of materials is studied and investigated.

The pin which is to be tested is clamped in a pin holder and is brought in contact with disk as shown in Fig. 3. The wear track of 100 mm is fixed. The speed of disk is set at 350 rpm. The time duration for each trial is of 5 min, and readings are directly displayed in a digital display. The load applied on the pin is of 50 N and 100 N. All the specimens of 6 mm diameter are tested on pin-on-disk machine to know the effect of tribological behavior on various gear steel alloys.

3.7 Wear Test

- The disk surface is cleaned by emery paper and spraying acetone.
- The pin specimen which is to be tested is mounted on a pin holder by Allen key.
- The speed, load and duration of test are decided as per design condition (Fig. 1).
- Before starting wet test, it is ensured that the oil level is maintained in the oil chamber.
- The disk portion is covered with oil cap and ensuring proper supply of oil.
- The test is conducted, and the behavior of wear, coefficient of friction and frictional force are investigated and compared.

4 Results and Discussion

The aim of the experiment was to study the effect of friction and wear on behavior of gear steels used in PGT. The experiments are carried out for different materials such as EN8, 20MnCr5, EN19, EN24 and MS at varying load conditions of 50 N and 100 N at constant sliding speed of 350 rpm. The tests are conducted on a pin-on-disk machine for dry as well as wet conditions for time duration of 5 min. The lubricant used for the wet condition is castor oil (20W40) which is more suitable for PGT. The results obtained are summarized in Table 2.

4.1 Variation of Wear, FF and COF for En8 (Dry Test, Load—50 N)

Figure 4 shows the variation in the wear, FF and COF for EN8 under the load of 50 N for dry test condition. From Fig. 4, it is observed that there is continuous increase in wear with some fluctuations and then wear remains almost

constant after 4 min, whereas there is an increase in FF with respect to time which continues till 100 s, after that it nearly becomes constant with little fluctuations. Also COF increases rapidly at beginning of test, but after 40 s it undergoes continuous fluctuations.

4.2 Comparison of Wear of EN8, 20MnCr5, EN19, EN24 and Mild Steel (Dry Test, Load—50 N)

Figure 5 shows the comparison of wear for dry condition under a load of 50 N for all materials, i.e., EN8, 20MnCr5, EN19, EN24 and mild steel. From Fig. 5, it is observed that the wear in 20MnCr5 is highest among all materials, while the wear is lowest for EN8. Also, during the commencement of test the increase in wear is maximum for 20MnCr5 and EN19, while in case of other three materials the increase in wear is almost gradual throughout the test. For 20MnCr5, the increase in wear occurs at a very slow rate after 80 s. The maximum wear in 20MnCr5 is due to the presence of very less amount of carbon in it, i.e., only 0.21% carbon. The wear in EN8 is minimum due to the presence of high amount of carbon in it, i.e., 0.39% carbon.

4.3 Comparison of FF for EN8, 20MnCr5, EN19, EN24 and Mild Steel (Dry test, Load—50 N)

Figure 6 shows the comparison of frictional force for dry condition under a load of 50 N for all materials, i.e., EN8, 20MnCr5, EN19, EN24 and mild steel. From Fig. 6, it is observed that the FF is maximum in the case of EN8 material, whereas in the case of 20MnCr5 the frictional force is minimum. Also, during the commencement of test there is very rapid increase in frictional force for all materials, but after 60 s the frictional force remains nearly constant for all materials except EN8. In EN8, the increase in frictional force continues till 230 s. Also, comparing Fig. 6 and Fig. 5, it is observed the material having highest wear (20MnCr5)

Table 2 Experimental result

Material	Load (N)		Wear (μm)	Frictional force (N)	Wet		
	Dry	Wet			Dry	Wet	Wet
EN8	50	50	185	33	29.5	2.6	
	100	100	1211	100	36.72	0.09	
20MnCr5	50	50	890	12	18.2	3.6	
	100	100	2044	34.50	27.31	0.02	
EN19	50	50	430	36.5	19	2.25	
	100	100	1954	51.65	36.68	0.09	
EN24	50	50	300	42	22	2.65	
	100	100	1971	35.54	39.50	0.02	
M.S.	50	50	590	105	19	2.35	
	100	100	1537	63.17	32.90	3.09	

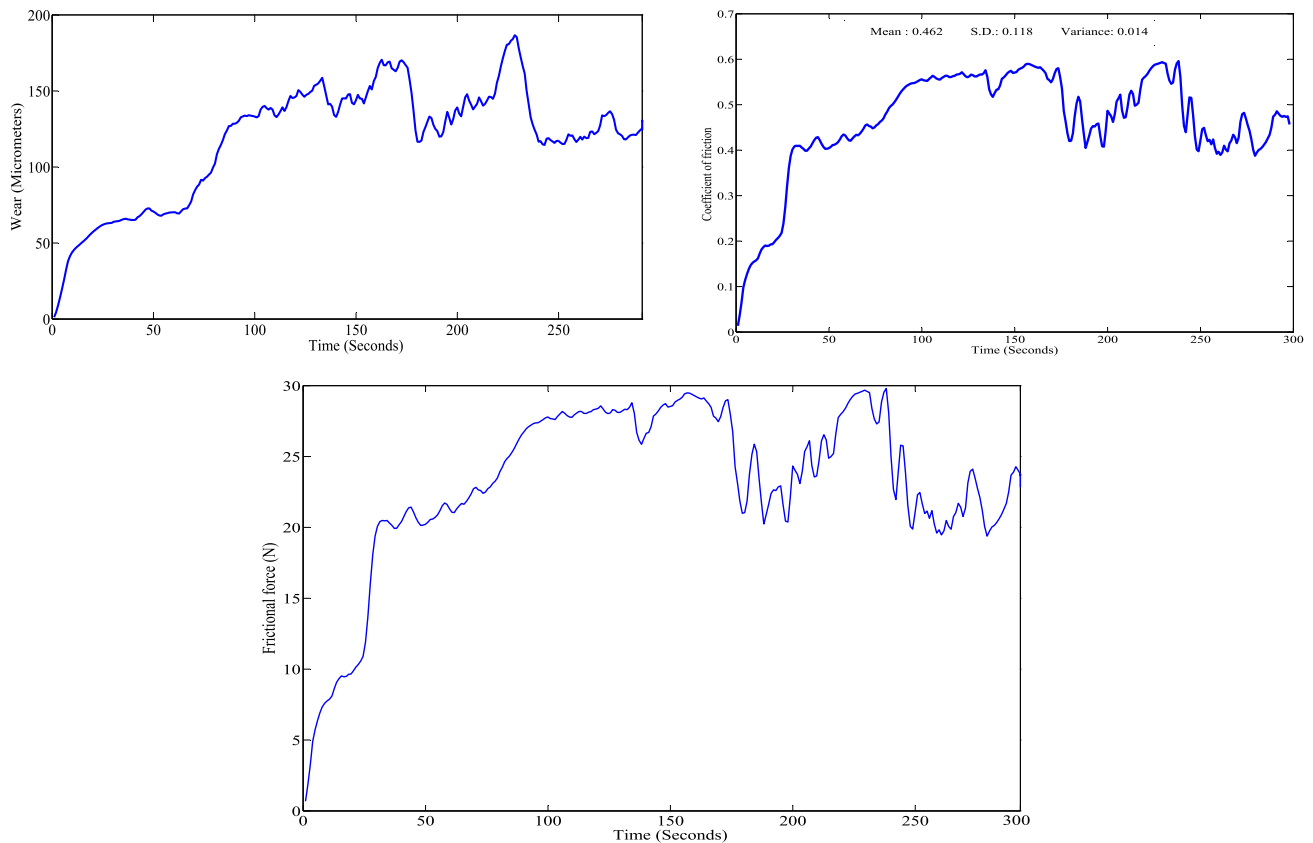
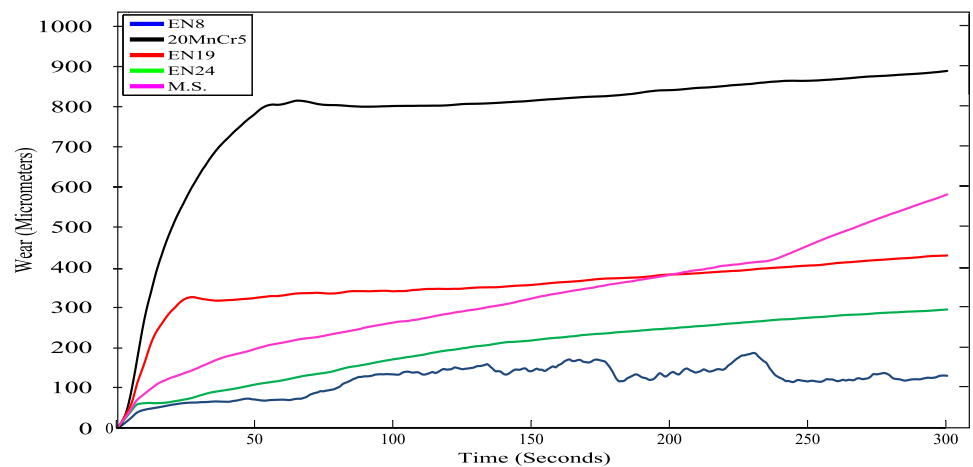


Fig. 4 Variation of Wear, FF and COF for En8 (dry test, load—50 N)

Fig. 5 Comparison of wear for EN8, 20MnCr5, EN19, EN24 and mild steel (dry test, load—50 N)



results in lowest frictional force and the material having lowest wear (EN8) results in highest frictional force.

4.4 Variation of Wear, FF and COF for EN8 (Wet Test, Load—50 N)

Figure 7 shows the variation in the wear, FF and COF for EN8 under the load of 50 N for wet test condition. From

Fig. 7, it is observed that initially at commencement of test there is rapid increase in wear, later the increase in wear becomes gradual, and it continues throughout the test. Also there is very high increase in FF at beginning of test, but after that there is slightly decrease in it and then remains nearly constant. In the case of COF, there is rapid increase at commencement of test, but immediately

Fig. 6 Comparison of FF for EN8, 20MnCr5, EN19, EN24 and mild steel (dry test, load—50N)

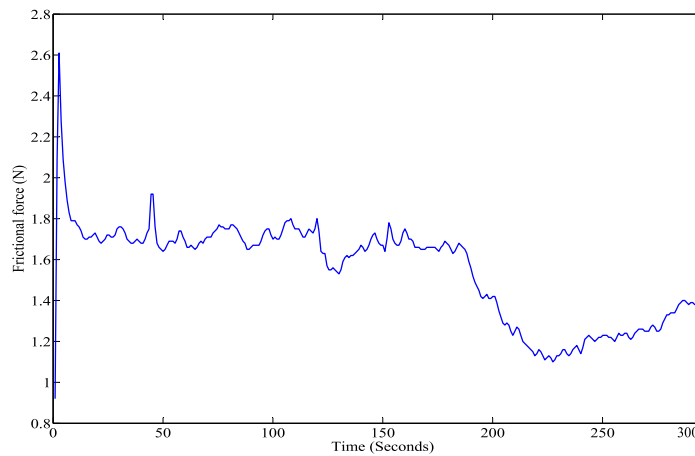
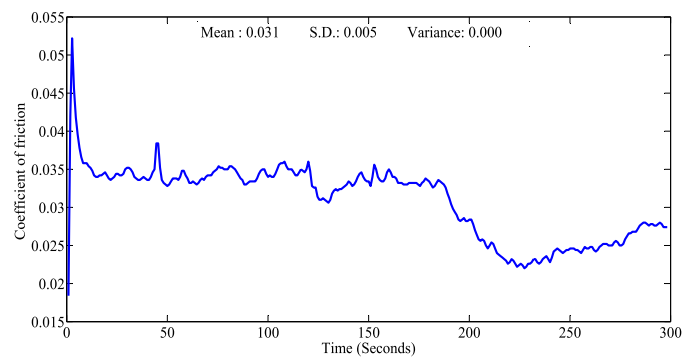
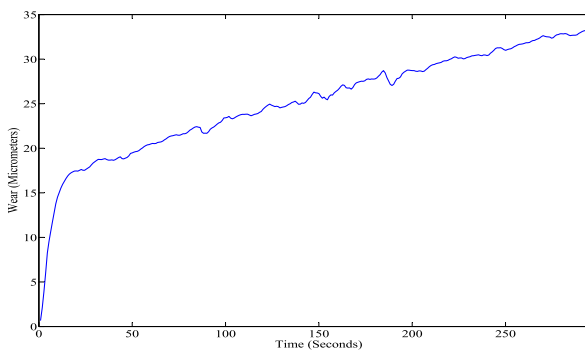
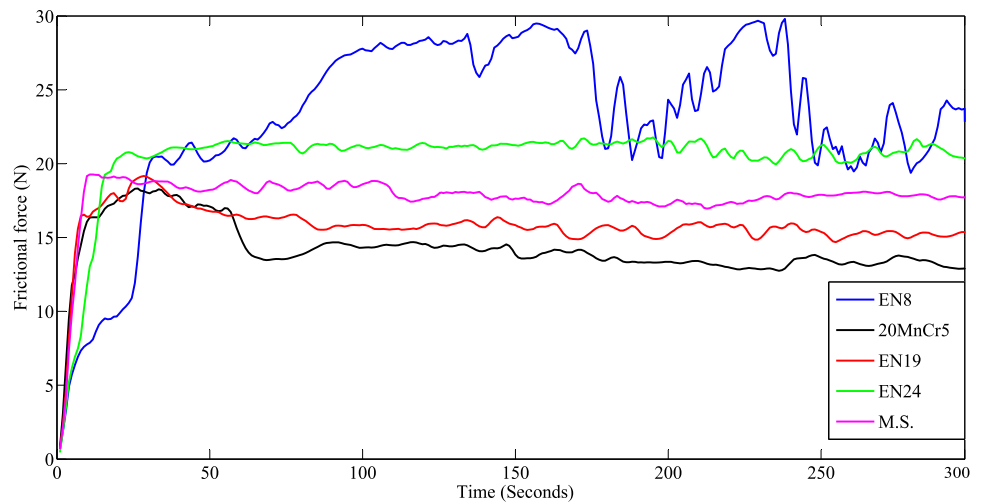


Fig. 7 Variation of wear, FF and COF for En8 (wet test, load—50 N)

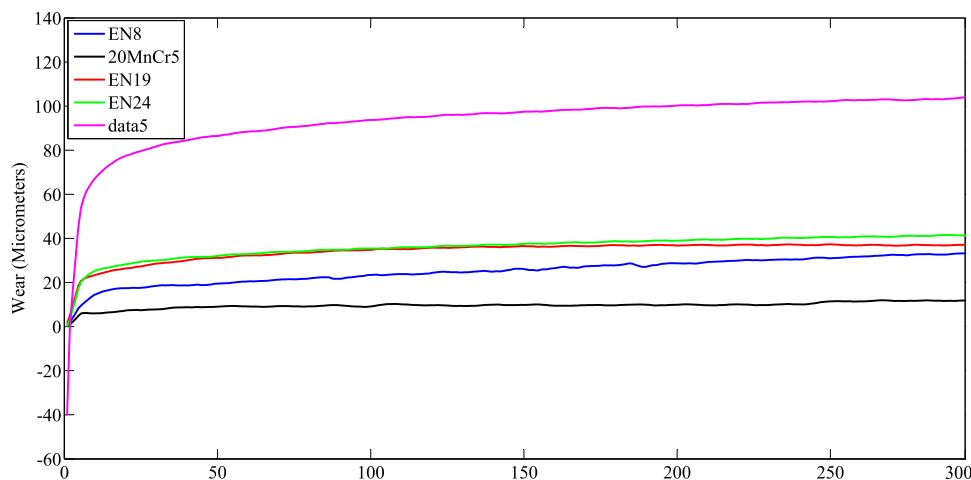
after that it decreases and then after some time it becomes almost constant with small amount of fluctuations.

4.5 Comparison of Wear of EN8, 20MnCr5, EN19, EN24 and Mild Steel (Wet Test, Load—50 N)

Figure 8 shows the comparison of wear with respect to time for wet condition under a load of 50 N for all

materials, i.e., EN8, 20MnCr5, EN19, EN24 and mild steel. From Fig. 8, it is observed that the wear in mild steel is highest among all materials, while the wear is lowest for 20MnCr5. Also, during the commencement of test the increase in wear is maximum for all materials and after that the wear remains almost constant for all materials, except EN8 and mild steel. In case of these two materials, the increase in wear continues throughout the test at a very

Fig. 8 Comparison of wear for EN8, 20MnCr5, EN19, EN24 and mild steel (wet test, load—50 N)

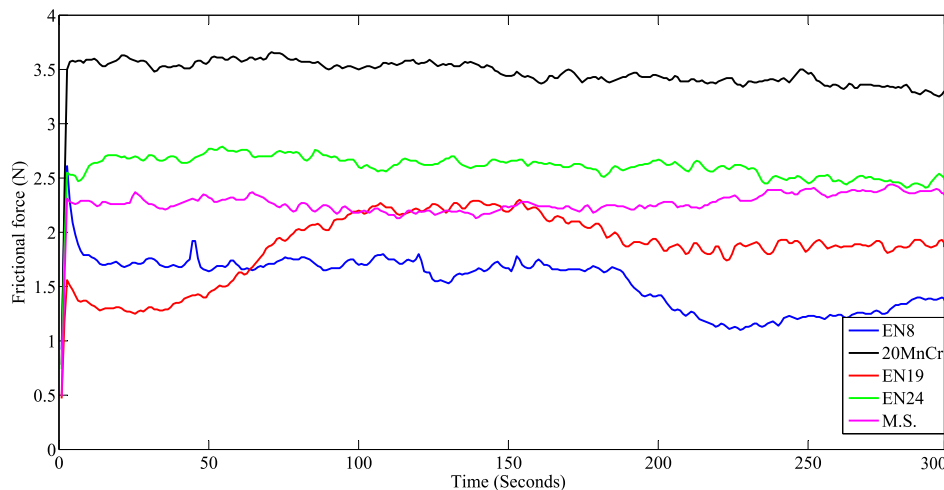


slow rate. By the use of lubricant, the wear of all materials is significantly reduced. The maximum wear in mild steel is due to the presence of very less amount of carbon (i.e., 0.20% carbon).

4.6 Comparison of FF for EN8, 20MnCr5, EN19, EN24 and Mild Steel (Wet Test, Load—50 N)

Figure 9 shows the comparison of FF for wet condition under a load of 50 N for EN8, 20MnCr5, EN19, EN24 and mild steel. From Fig. 9, it is observed that the FF is maximum for 20MnCr5 and it is minimum for EN8 material. Also, during the commencement of test there is very rapid increase in FF for all materials, but later it becomes almost constant throughout the test with small fluctuations. The maximum FF in 20MnCr5 may be due to the presence of very less amount of carbon (i.e., 0.21% carbon). The FF in EN8 is minimum may be due to presence of high amount of carbon (i.e., 0.39% carbon).

Fig. 9 Comparison of FF for EN8, 20MnCr5, EN19, EN24 and mild steel (wet test, load—50 N)



4.7 Variation of Wear, FF and COF for EN8 (Dry Test, Load—100 N)

Figure 10 shows the variation in the wear, FF and COF for EN8 under the load of 100 N for dry test. From Fig. 10, it is observed that initially there is gradual increase in wear up to 70 s; then, there is rapid increase in wear from 70 to 150 s and then the wear of EN8 remains almost constant till the end of test. Also in the case of FF, it starts increasing after 15 s; then, the increase in FF continues till 140 s. After 140 s, FF becomes nearly constant. In the case of COF, it increases at a faster rate after 15 s till 140 s; then, it remains almost constant throughout the remaining test duration with some fluctuations.

4.8 Comparison of Wear of EN8, 20MnCr5, EN19, EN24 and Mild Steel (Dry Test, Load—100 N)

Figure 11 shows the comparison of wear with respect to time for dry condition under a load of 100 N for EN8,

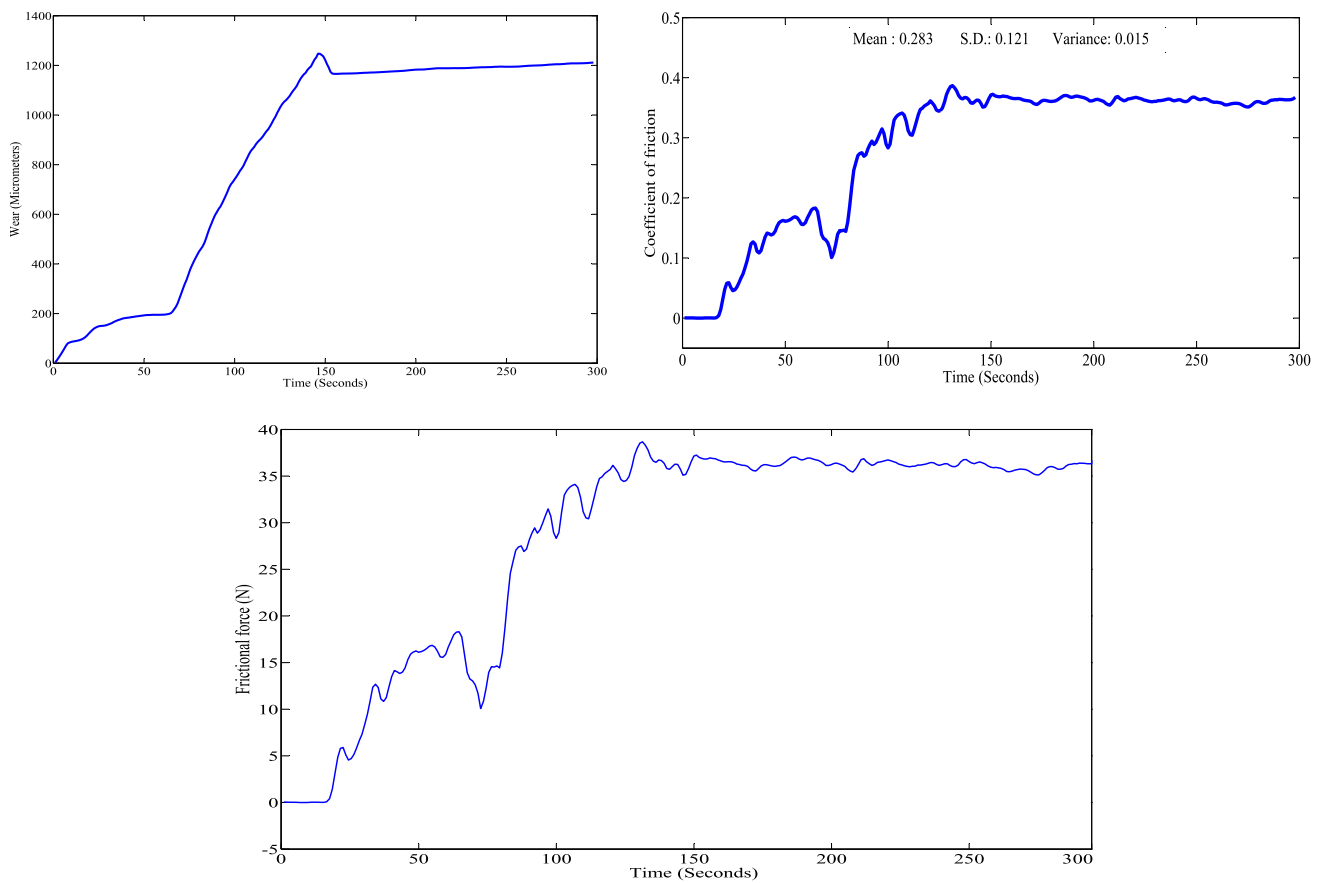
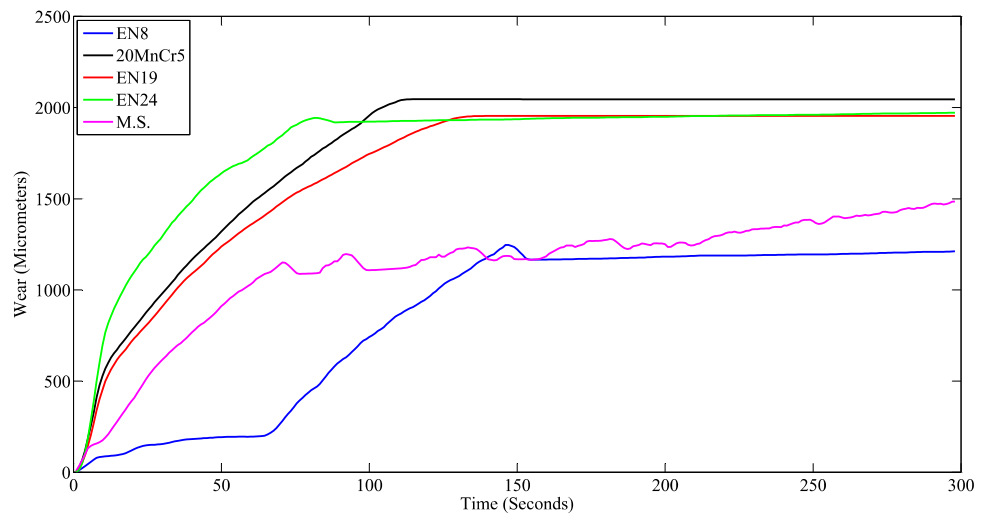


Fig. 10 Variation in the wear, FF and COF (dry test, load—100 N)

Fig. 11 Comparison of wear for EN8, 20MnCr5, EN19, EN24 and mild steel (dry test, load—100 N)



20MnCr5, EN19, EN24 and mild steel. From Fig. 11, it is observed that the wear in 20MnCr5 is highest among all materials, while the wear is lowest for EN8. Also, during the commencement of test the increase in wear is maximum for all materials except EN8. In case of EN8, initial increase in wear is gradual; then, suddenly there is a rapid

increase up to 1200 μm; then, after that the wear remains almost constant. The wear of all the materials remains constant after rapid increase at beginning except mild steel. The maximum wear in 20MnCr5 is due to the presence of very less amount of carbon (i.e., 0.21% carbon). The wear

in EN8 is minimum due to the presence of high percentage of carbon (i.e., 0.39% carbon).

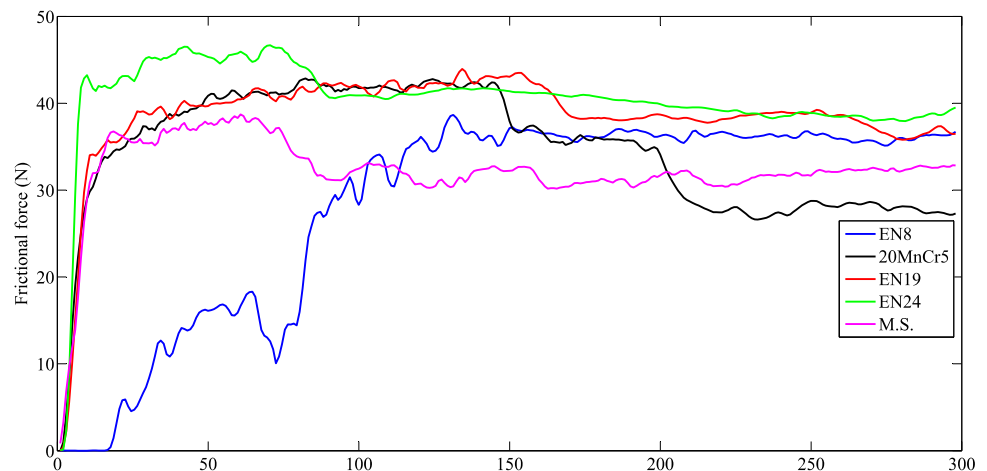
4.9 Comparison of FF for EN8, 20MnCr5, EN19, EN24 and Mild Steel (Dry Test, Load—100 N)

Figure 12 shows the comparison of FF with respect to time for dry condition under a load of 100 N for all materials. From Fig. 12, it is observed that the FF is maximum in case of EN24 material, whereas in case of 20MnCr5 it is minimum. Also, during the commencement of test there is very rapid increase in FF for all materials except EN8. In case of EN8 the FF increases after 10 s of commencement of test. The FF of EN19, mild steel and EN8 almost remains constant with little amount of fluctuations, whereas in the case of 20MnCr5 and EN24 there is little decrease in FF after 100–120 s. Also from Figs. 11 and 12, it is observed the material having highest wear (20MnCr5) shows lowest FF and the material devouring lowest wear (EN8) is shows very high FF.

4.10 Variation of Wear, FF and COF for EN8 (Wet Test, Load—100 N)

Figure 13 shows the variation in the wear, FF and COF for EN8 under the load of 100 N for wet test condition. From Fig. 13, it is observed that at the commencement of test there is rapid increase in wear of EN8 and after 120 s the increase in wear becomes gradual with respect to time which continues throughout the test duration. Frictional force shows continuous little variation with respect to time for remaining test duration. The FF is very small due to the use of lubricant, and it fluctuates between 0 and 0.1 N only. Same is the case for COF which is very small and varies between 0 and 0.001 throughout the test duration.

Fig. 12 Comparison of FF for EN8, 20MnCr5, EN19, EN24 and mild steel (dry test, load—100 N)



4.11 Comparison of Wear of EN8, 20MnCr5, EN19, EN24 and Mild Steel (Wet test, Load—100 N)

Figure 14 shows the comparison of wear against time for EN8, 20MnCr5, EN19, EN24 and mild steel for 100 N loading condition. From Fig. 14, it is observed that wear for all the materials is less. EN8 has the highest wear rate, i.e., 100 μm . On the other hand, 20MnCr5 has the lowest of wear rate, i.e., 34 μm . Other materials EN24, EN19 and M.S. have the value of 130 μm , 52 μm and 36 μm . The variation in the wear rate of all these materials is due to their chemical composition and the lubricant used. Due to the use of lubricant, one can see that there is great change in the value of wear rate. EN8 has the highest percentage of carbon content (i.e., 0.39%), but due to the use of lubricant its wear rate is maximum. On the other hand, 20MnCr5 has the lowest carbon content (i.e., 0.21%), but due to the use of lubricant its wear rate is minimum. From the above discussion, it is seen that lubricant plays an important role for the wear rate. EN19, M.S. and EN24 have less percentage of carbon content than EN8. Hence, their wear rate is less as compared to wear of EN8.

4.12 Comparison of FF for EN8, 20MnCr5, EN19, EN24 and Mild Steel (Wet test, Load—100 N)

Figure 15 shows the comparison of FF with respect to time for EN8, 20MnCr5, EN19, EN24 and mild steel for 100 N loading condition. The test was conducted for wet condition, and the lubricant used was SAE 20W40. From Fig. 15, it is observed that the FF for all the materials is very less due to the use of lubricant. M.S. has the highest value of FF, i.e., 3.2 N. On the other hand, EN19 has the lowest value of FF, i.e., -0.15 N. Other materials EN8, EN24 and 20MnCr5 have the value of FF as 0.15 N, 0.1 N and 0.05 N. The variation in FF for all these materials is due to their chemical composition and the lubricant used.

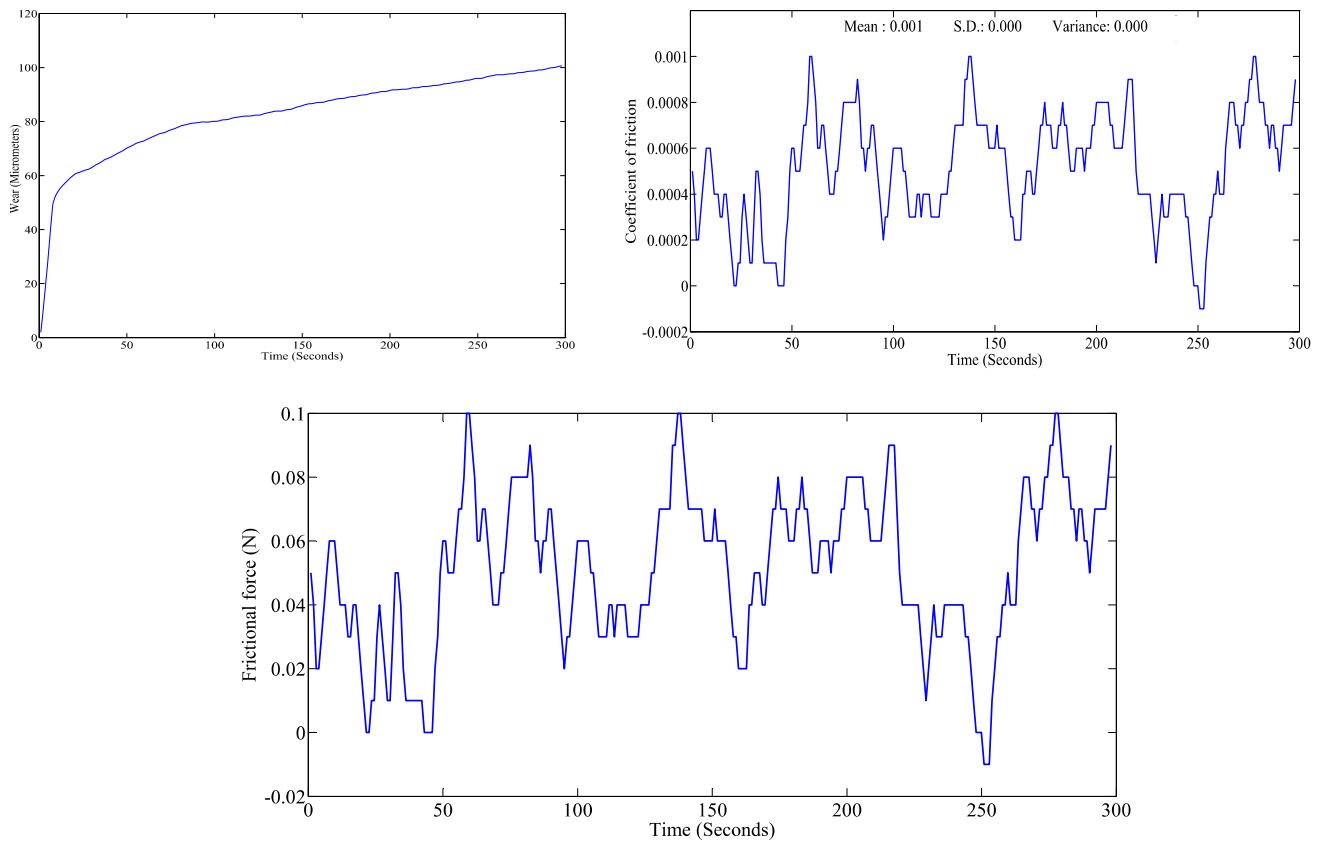
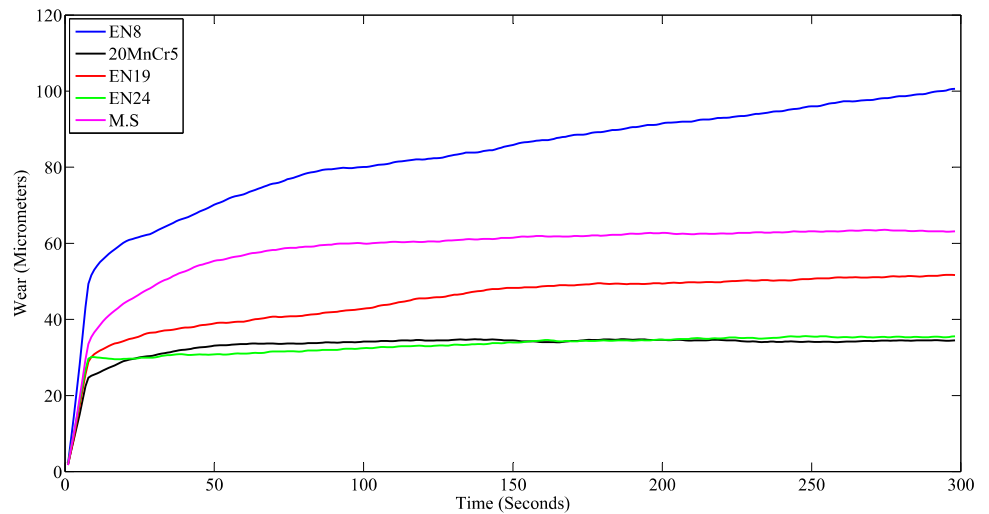


Fig. 13 Variation in the wear, FF and COF (wet test, load—100 N)

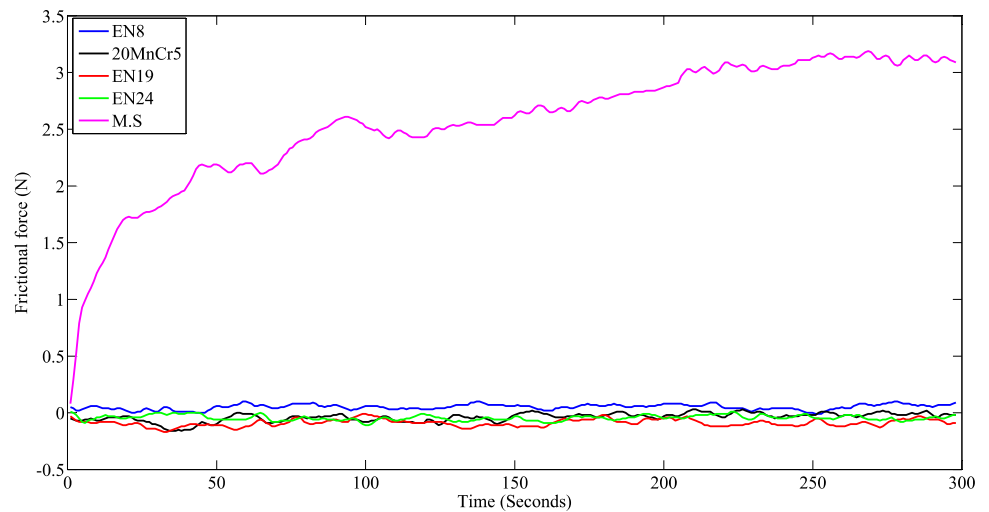
Fig. 14 Comparison of wear for EN8, 20MnCr5, EN19, EN24 and mild steel (wet test, load—100 N)



The wear rate and FF are inversely proportional to each other which mean that if the wear rate is decreased the FF is increased. The carbon content plays the important role in the wear rate, and it is followed by nickel. EN19

has 0.38% of carbon and 0% of nickel. On the other hand, EN24 has 0.41% of carbon and 0.1% of nickel. Due to this, EN19 has less FF than EN24. M.S. contains 0.21% of carbon due to which its FF is highest.

Fig. 15 Comparison of FF for EN8, 20MnCr5, EN19, EN24 and mild steel (wet test, load—100 N)



5 Conclusions

1. In this paper, the effect of wear and friction on different materials is studied by using a pin-on-disk apparatus. From experimental investigations, EN8, 20MnCr5, EN19, EN24 and M.S. show that if the wear rate decreases then the frictional force increases except for M.S. It also shows that the COF is maximum for minimum wear rate and as the wear rate increases COF decreases except for M.S.
2. 20MnCr5 shows the highest wear among all the other materials. This may be due to the presence of less amount of carbon content. The wear performance of steels is significantly governed by the chemical composition of material. Wear in carbon steel is significantly reduced due to more carbon percentage.
3. As this work is a part of design of planetary gear train for heavy weight CNC bending machine to study the tribological behavior of gear steels, the above-summarized result shows that EN8 is suitable for the design of planetary gear train where wear is the main criteria.

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Compliance with Ethical Standards

Conflict of interest The authors declare that there is no conflict of interests regarding the publication of this paper.

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