Wear Behaviour of SAE 4340 Steel in Comparison with Single Test Specimen

Nadendla SRINIVASABABU*

*Corresponding author
Fibrous Composites Research Lab, Department of Mechanical Engineering,
Vignan's Lara Institute of Technology & Science,
Vadlamudi – 522 213, Andhra Pradesh, India,
sbabunva@gmail.com, drnsbabu_vlits@vignanac.in

DOI: 10.13111/2066-8201.2020.12.3.18

Received: 18 May 2020/ Accepted: 28 July 2020/ Published: September 2020

Abstract: *This study addresses the progressive damage of a surface/specimen/component caused by another substance in relative motion. This could cause the change in geometry, dimensions of the part which loses the practical functionality. So, an attempt was made to study the wear behavior of SAE 4340 steel using a pin-on-disc wear test machine at different loading, test speed, and time. Two cases viz. (1) single steel specimen, (2) multiple specimens were considered for the wear test and the obtained wear (µm), and frictional force (N) was compared.*

Key Words: *SAE 4340 steel, single and multiple test specimens, wear, frictional force*

1. INTRODUCTION

The name 'Tribology' comes from the Greek word 'tribos' (friction). Tribology can be defined as the science and technology of interacting surfaces in relative motion.This term was first used in the Jost report in 1966 and finds its application in friction, wear, and lubrication.

The main driving force for the introduction/advancement of research in tribology has been the facilitation of daily activities by reducing friction, especially in areas such as weapons, tools, crafts/constructions etc.

Stone door sockets, bearings for wheeled vehicles, and bearings for stone potter's wheel were used in Mesolithic period 11000-5500 years ago. These 5000 years old bearings were lubricated with bitumen [1].

Wear occurs because of the relative motion of working parts and is an inevitable companion of friction.

This progressive damage involves loss of material during parts functioning. The tribological pairs are supplied with a sufficient quantity/ amount of lubrication to avoid excessive wear and damage which would be present if the friction resistance to motion is reduced.

The volume of the material lost from the work surface per unit sliding distance in sliding or rolling contact is called wear rate. Wear rate depends on load, sliding speed, temperature, thermal-chemical properties of the materials under dry/un-lubricated conditions in sliding contact [2].

When two surfaces are in relative motion, rubbing occurs resulting in degradation of the coating, which was termed as sliding wear. They apply the most important governing parameters of sliding wear. But the coefficient of friction was influenced by a load, the sliding velocity [3].

Wear increases with the sliding distance and time, when two work surfaces were in sliding with each other. Accordingly, the wear rate can be defined as material removal rate/dimensional change per unit time or sliding distance.

Archard proposed model in 1953 was used for estimating the material removal rate in sliding wear and is expressed by equation [4].

$$Q = \frac{K\,W}{H}$$

where Q = Volume of the material removed from the surface by wear per unit sliding distance,

W = Normal load applied between the surfaces,

H = indentation hardness of the softer surface,

K = Dimensionless Archard wear coefficient, less than unity. The value of K is used to understand the severities.

Due to the ignorance of physics & physical metallurgy of deformation metal by Archard, a new wear mechanism was developed in 1973 depending on dislocation theory, fracture, and plastic deformation of metal near a surface [5].

In many tribological systems, the transfer of material occurs from one component of a sliding pair to another. With the use of optical microscopy, scanning electron microscopy (SEM), transmission electron microscopy, structural and chemical information during the material transfer and debris particles can be obtained [6].

Several common features of various materials under different rubbing contacts were highlighted by the Third Body Approach (TBA). By this approach mechanical engineers are able to study the dynamics of the interfacial problem [7].

The sequence of events in sliding wear was outlined. Either/both the components experience the large plastic strains due to the local contacts in sliding systems. This plastic deformations change the microstructure of the near-surface that tends the local material shear. Deformed pieces of the material were combined with the counter face material which produces fine-grained material.

The transfer of the material occurs as loose debris [8]. Using CFT I multifunctional surface comprehensive tester tribological behavior of AISI 4340 steel was studied at a temperature of 25ºC. Worn surface and subsurface were observed using SEM [9].

AISI/SAE 4340 steel is considered a standard for comparing other ultra-high strength steels. This steel is usually oil quenched, possesses high ductility, toughness, strength, and deep hardenability along with high fatigue and creep resistance.

Uses of this steel include high strength in heavy sections, severe service conditions, and resistance to temperature-related embrittlement [10].The experimental work conducted on AISI 4340 steel was quite limited and is observed after the literature review. So, an attempt is made in this work to study the sliding wear behavior of SAE 4340 steel under two cases.

In the first case, different specimens were considered at various loading conditions; the speed was evaluated to experimentally study the wear and the frictional force without lubrication.

Secondly, one specimen was taken in the entire study of wear and frictional force at a different speed, load, and time and the results were published elsewhere [11]. Then a comparison was made among these conditions for understanding the wear phenomenon.

2. MATERIALS AND METHODS

2.1 Basic tests on SAE 4340 Steel

In this work, SAE 4340 steel was chosen for studying the wear behavior experimentally and it was procured from KALVA Enterprises Private Limited, Hyderabad. Here onwards SAE/AISI 4340 or steel is used in the description of the present paper. Initially, the rust on the material is cleaned with the help of emery paper of 600 and 1/0 respectively and is wiped off with a neat cloth. Preliminary basic tests viz. hardness, tensile, flexural, impact were conducted on this steel along with the evolution of microstructure.

Using a Metascope Metallurgical Microscope type the microstructure of the steel was found at 100X magnification and an etchant of marbles reagent was used. This test was conducted at Jyothi Spectro Analysis Ltd., Hyderabad. MRB-250 Rockwell hardness tester was employed to conduct a hardness test on the specimens by applying a major load of 150 kg suitable for deep case hardened steel through changing the position of the hand lever from normal to load position up to 15s. The major load was slowly removed and the reading corresponded to ‘C’ scale was noted.

By using a 40 Tons capacity Hydraulic Operated UTM machine (Fig. 1, ASTM E8-11) tensile, a bend test (Fig. 2, ASTM E290-14) was conducted on SAE 4340 steel specimens and the average values were determined.

According to ASTM E23-82 an impact test was done on the samples using AIT – 300 Izod/Charpy impact tester as shown in Fig. 3.

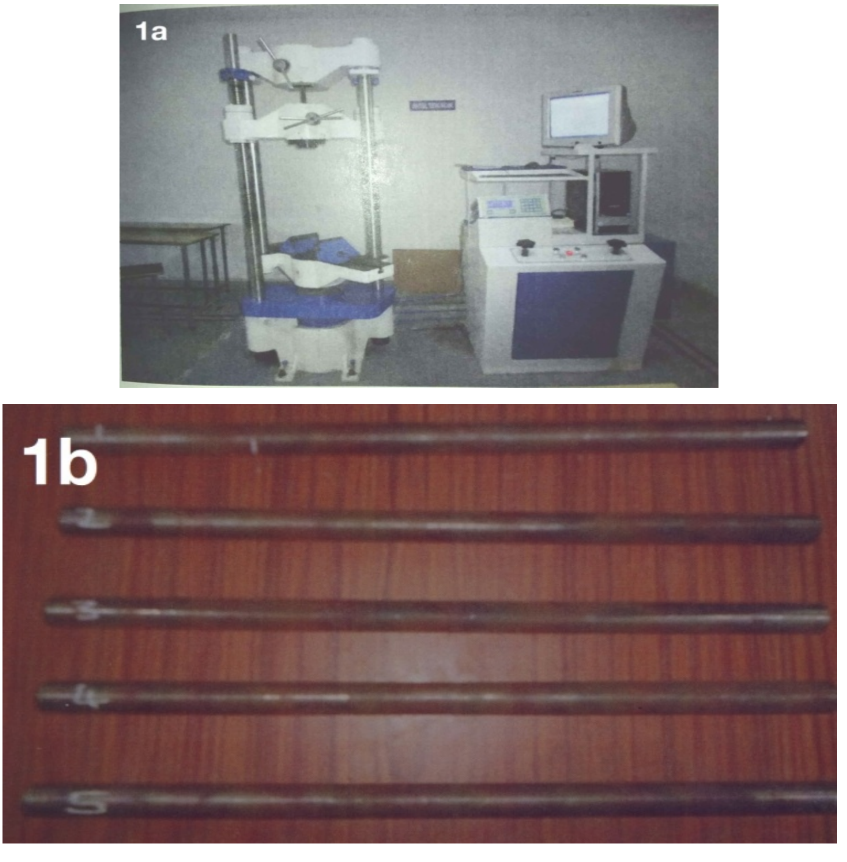

Fig. 1 (a) Universal testing machine, (b) Specimens

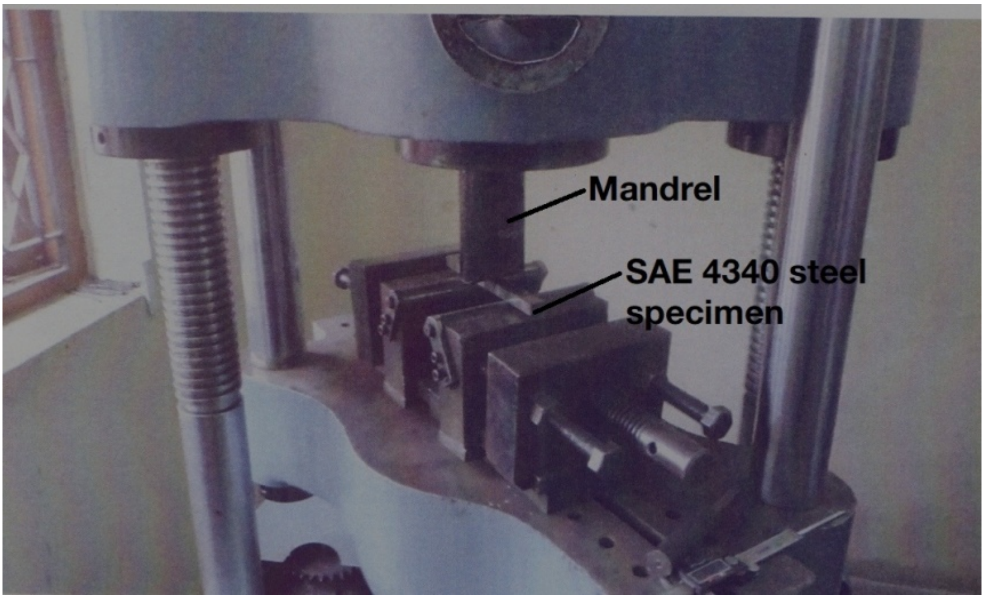

Fig. 2 Bend test specimen arrangement

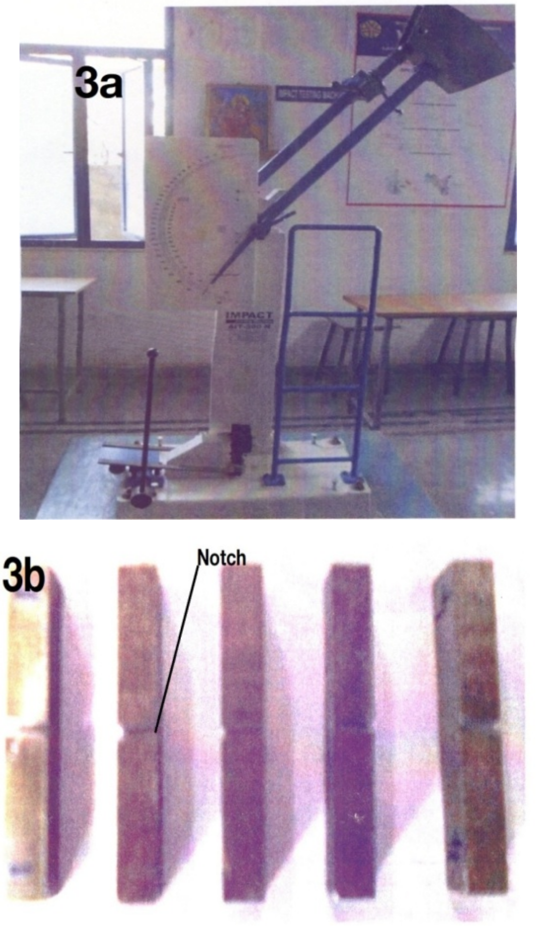

Fig. 3 (a) Izod/ Charpy Impact tester, (b) Specimens after notch cut

2.2 Pin-On-Disc Wear Test on SAE 4340 steel

Typically, the specimen should be cylindrical with a diameter of 10 mm (Fig. 4). It was inserted tightly in a fixture and was kept in contact with the disc of the TR-20 Wear Testing Machine as shown in Fig. 5, supplied by Ducom Instruments Pvt. Ltd., Bangalore. The temperature maintained during the test was 23ºC and a standard disc supplied by DUCOM was used in the entire wear experiments.

Fig. 4 SAE 4340 Steel specimens for wear test

Fig. 5 (a) Wear testing arrangement, (b) specimen during wear test

The test was conducted according to ASTM G 99 at different process conditions. One set of speeds 400, 700, 1000, 1300, and 1600 rpm were used at loads of 3, 4.5, 6, 7.5 and 9kg. Here the wear test is conducted on five specimens at each speed-load conditions of the test and the average values of wear and frictional force were determined. In another case, a single specimen was considered throughout the experimentation at a speed, load, test time of 225 (N1), 450 (N2) and 675 (N3) rpm, 2, 3 and 4 kg and 200 (t1), 600 (t2), 800 (t3), 900 (t4), 300 (t5), 200 (t6), 333 (t7) s, respectively. The combinations of the test parameters considered in this experimentation were N1-t1, t2, t3, t4, N2-t5, N3-t6, t7. After each test, the specimen was wiped off with a neat cloth for removal of adhered debris on the surface [11].

3. RESULTS AND DISCUSSIONS

The microstructure of SAE 4340 steel was shown in Fig. 6, which consists of carbides in the matrix of tempered martensite. The average value of the hardness of the steel was 27.5 HRc. Tensile, bend, and impact tested specimens are shown in Fig. 7, 8, and 9, respectively. SAE steel exhibited tensile strength, modulus of 794.42 MPa, 205 GPa, respectively. In three-point bend mode, the steel had exhibited a flexural strength of 1.42 GPa. Ductile failure was observed on Charpy impact tested specimens and showed impact strength of 272kJ/m^2.

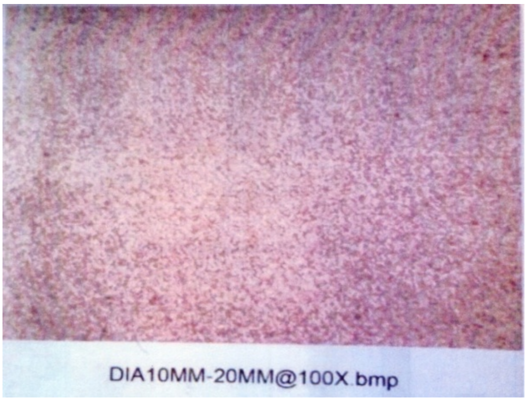

Fig. 6 Microstructure of SAE 4340 steel

Fig. 7 Tensile tested specimens

Fig. 8 Bend tested specimens

Fig. 9 Impact tested specimens

At 400 rpm disc speed, the wear of steel was decreased with an initial increase in load; thereafter it was increased up to 7.5kg load, and then decreased, Fig. 10. The frictional force was increased linearly up to 6 kg load; further the frictional force was increased considerably. Wear and the frictional force of SAE 4340 steel at 700rpm against load were graphically shown in Fig. 11. The wear of the specimens at the starting load was 2.3 times more than that of the maximum load. Whereas the frictional force at the maximum load was 4.7 times that exhibited at 3kg load.

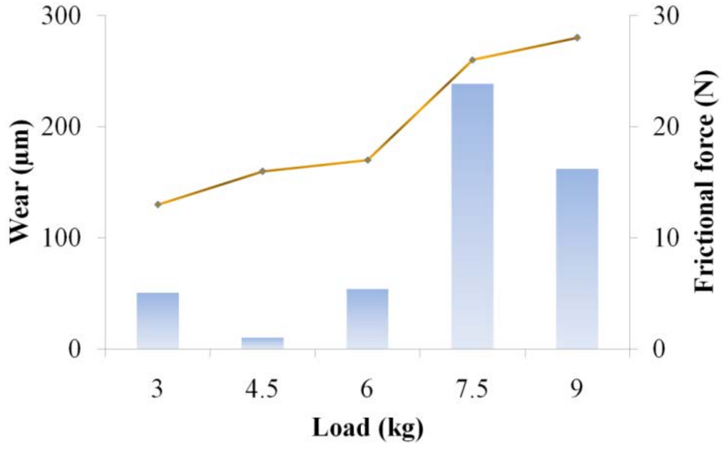

Fig. 10 Wear, frictional force of SAE 4340 steel at N = 400rpm

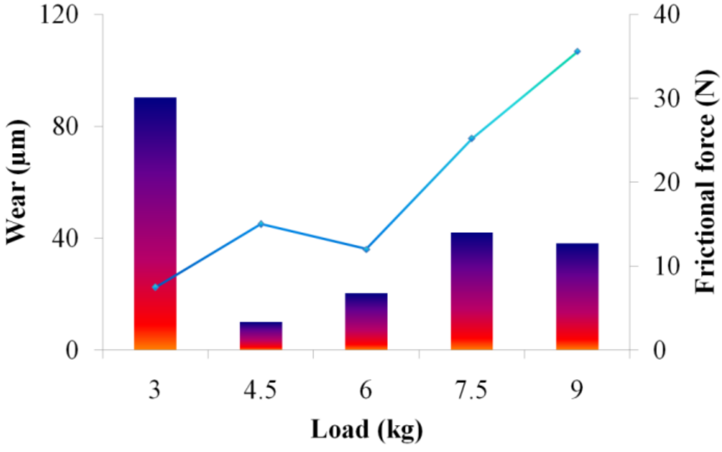

Fig. 11 Wear, frictional force of SAE 4340 steel at N = 700rpm

The specimens tested at 1000rpm had exhibited an increase in wear with an increase in load applied except at 7.5kg and this is visible in Fig. 12. At 1300rpm, the wear of the specimens at the lowest load was low, and then it was increased considerably, see Fig. 13.

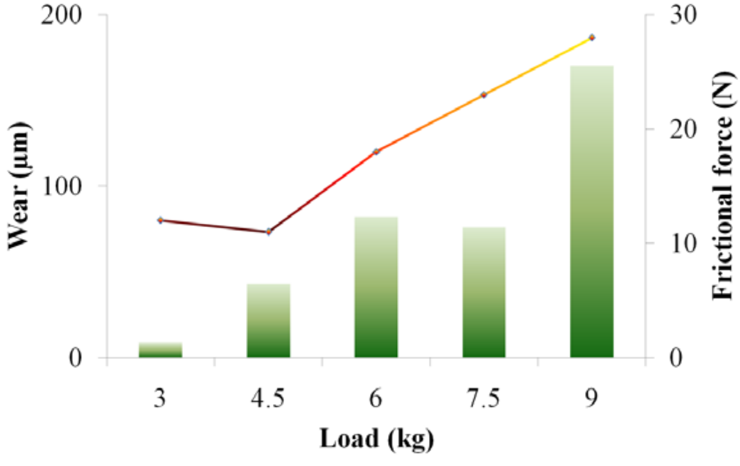

Fig. 12 Wear, frictional force of SAE 4340 steel at N = 1000rpm

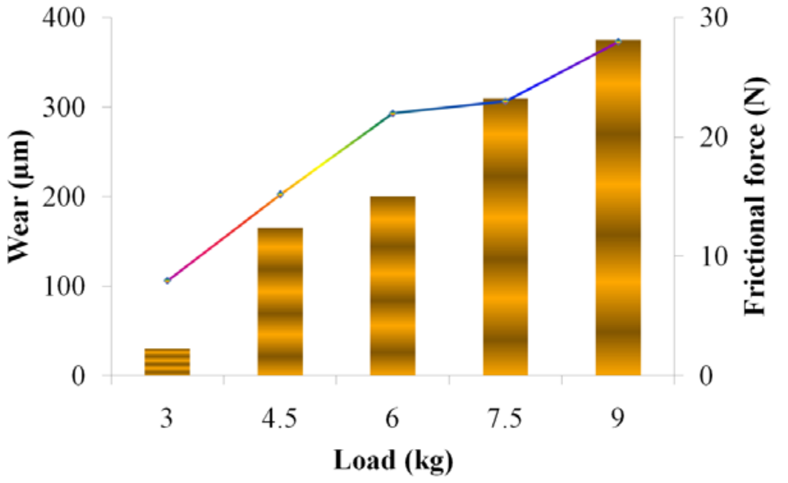

Fig. 13 Wear, frictional force of SAE 4340 steel at N = 1300rpm

Wear at the maximum load was 12.5 times more than that showed at a minimum load of 3kg. Wear on the specimens was increased with increase in load up to 7.5kg and thereafter it was decreased.

The maximum wear exhibited was 3.6 times more than that shown at 3kg load as identifiable from Fig. 14.

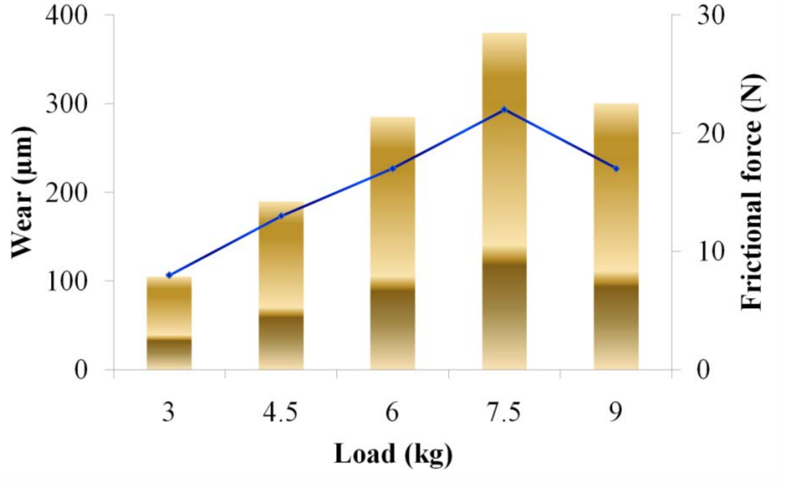

Fig. 14 Wear, frictional force of SAE 4340 steel at N = 1600rpm

With an increase in load, the frictional force was increase and this trend was experimentally seen at all the loads, speeds investigated for SAE 4340 steel except for the conditions of 700rpm – 6kg and 1600rpm – 9kg, respectively, where the frictional force slightly, reasonably decreased.

Wear and friction behavior of a single specimen SAE 4340 steel was graphically shown in Fig. 15 and 16, respectively.

Wear of the steel was increased with the combination of N1 – t1, t3, t4; N2 – t5 along with an increase in load which can be seen in Fig. 15.

At 225 rpm, 600s of the test, the wear of the specimen was decreased from 17 – 11µm with a load increased from 2-4kg in steps of 1 kg. N2-t6, t7 combinations had shown irregular wear patterns.

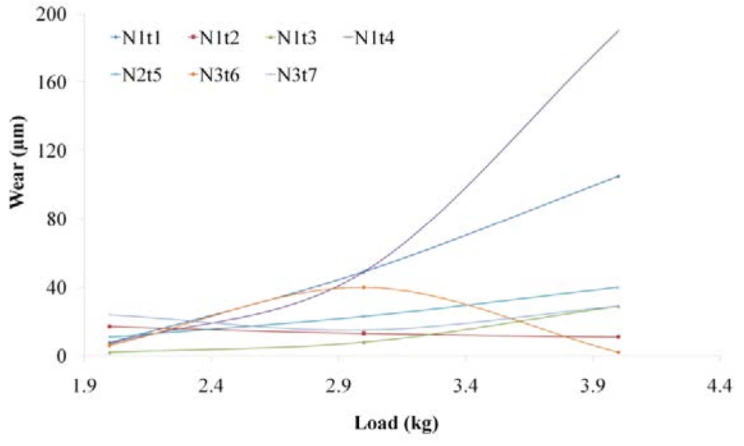

Fig. 15 Wear of SAE 4340 steel of single specimen at different N, t and loading

With an increase in load and the speed-time combinations of N1-t2, t3, t4; N2-t5; N3-t7 the frictional was increased, as in Fig. 16. However, N1-t1, N3-t6 combinations had shown an irregular trend of the frictional force with an increase in load. Wear of A356 cast composites samples was assessed on the pin on a disc machine. The authors reported that with increased loading the wear rate was increased. The coefficient of friction was also increased due to the localized adhesion of the worn debris to the specimen [12].

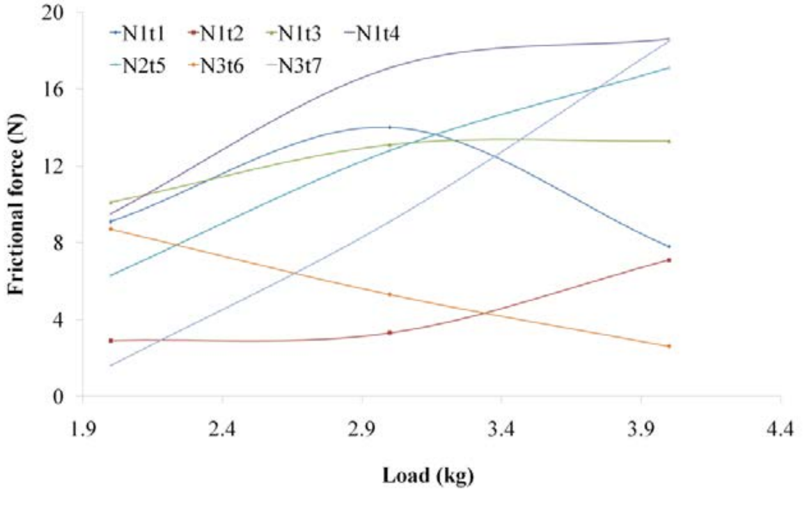

Fig. 16 Frictional force of SAE 4340 steel of single specimen at different N, t and loading

4. CONCLUSIONS

Pin-on-disc wear tests were successfully conducted on all steel specimens at different speeds, loading conditions, and test time. The highest wear was observed at 1600rpm disc speed, 7.5kg loading on steel specimens. Whereas the highest frictional force was exhibited by the steel at 700rpm, maximum load i.e. 9kg. In the wear test of a single specimen, the maximum wear was indicated by the specimens tested up to 900s, 225rpm and4 kg loading. At these conditions, the frictional force exhibited by the specimens was also high i.e. 18.6N when compared to the other results in this work.

REFERENCES

[1] T. Mang, K. Bobzin, T. Bartels, *Industrial Tribology: Tribosystems, Friction, Wear, and Surface Engineering*, Lubrication, 2011.
[2] J. Williams, *Engineering Tribology*, Cambridge UniversityPress, 2006.
[3] M. Roy, *Surface Engineering for Enhanced Performance Against Wear*, Springer, 2013.
[4] H. Czichos, T. Saito, L. Smith, *Hand Book of Material Measurement Methods*, Springer, 2006.
[5] N. P. Suh, The delamination theory of wear, *Wear*, **25**, pp. 111-124, 1973.
[6] P. Heilmannt, J. Don, T. C. Sun, D. A. Rigney, Sliding WearandTransfer, *Wear*, Vol. **91**, pp. 171-190, 1983.
[7] M. Godet, The third-body approach: a mechanical view of wear, *Wear*, **100**, pp. 437-452, 1984.
[8] D. A. Rigney, L. H. Chen And M. G. S. Naylor, Wear processes in sliding systems, *Wear*, **100**, pp. 195-219, 1984.
[9] H. Ma, G. Liang, M. Lv, Y. Huang, Y. Han, Investigation on Friction and Wear behavior of AISI 4340 Steel in Dry Sliding Condition, Tribology, *Mocaxue Xuebao/ Tribology*, **38**, pp. 59-66, 2018.
[10] J. R. Davies, *ASM Speciality Handbook: Tool Materials*, ASM, 1995.
[11] N. Srinivasababu, *Wear behavior of SAE 4340 steel – single specimen*, McGraw Hill Education India Pvt. Ltd., 2015.
[12] S. A. Alidokht, A. Abdollah-zadeh, H. Assadi, Effect of applied load on the dry sliding wear behavior and the subsurface deformation on hybrid metal matrix composite, *Wear*, **305**, pp. 291-298, 2013.