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Optimization using genetic algorithm of tribological behaviour of WC tool material

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In this investigation we have used a heuristic approach to optimize the process parameters in terms of tool wear rate. We have used the L8 orthogonal array design of experiments with three input parameters set at two levels. We have carried out the experimentation on two different processes *viz.* dry sliding and dry turning processes. An attempt has been made to achieve and validate the results obtained from these processes to check the repeatability of values in the same experimental environment. The tool material chosen for tool insert is Tungsten Carbide which is used in the manufacturing industries. We have optimised the results obtained on tribometer under the dry sliding process through a modern optimization technique *i.e.* genetic algorithm. The response surface methodology model (L8 orthogonal array) formed the basis for the development of genetic algorithm model through which we have defined the conditions. We have used the conditions of minimum tool wear for turning process, minimum coefficient of friction and minimum surface roughness for sliding process on a pin-on-disc test rig. It has been inferred that the sliding and turning processes under the conditions of no lubrication yielded analogous results. We have verified the same results practically by performing confirmation experiments on lathe machine for turning operation under the same experimental conditions.

Keywords: Wear, COF, Friction, Genetic algorithm, Tungsten carbide

1 Introduction

The ever-changing demands of the modern technical system, the environmental sustainability forms the major pillar for any manufacturing process[1]. Cooling or lubrication-based machining process or wet machining process have undesirable health issues on humans and ecology as the cooling processes were performed through the use of cutting fluids or lubricating oils[2]. Manufacturing industries extensively use lubricating oils and cutting fluids owing to the benefits they provide *i.e.* long tool life, high surface finish, easy chip removal, low temperature in the zone of cutting and reduced friction at the tool-work interface[3,4]. Effective lubrication has a substantial role in high-proficiency machining operations[5]. Kaynak[6] investigated the wear of tool for Nickel-Titanium alloy under dry and MQL conditions during the machining process and yielded that tool life enhanced under MQL condition. Krolczyk[7] investigated the workpiece surface topography under dry turning and with the usage of MQCL (Minimum Quantity Cooling Lubricant). They inferred MQCL yielded better results against dry turning[6,7]. However, the lubricants are associated with the numerous environmental problems involving their disposal as waste. A rapid increase has been recorded in the issues related to the environment. In recent times, the enforcement of environmental laws has increased economic problems for the manufacturing industries[8]. Another research claims that dry hard turning is beneficial due to safety concerned with the environment[9]. Dry turning is advantageous owing to elimination of cutting fluids cost and cost of fluid disposal system. This urge for the improved machined surface quality without deteriorating effects on the environment has imposed exploitation of a new research area, cutting tool materials. The manufacturing industries are now heading towards the new challenges with the demand for tougher steels[10]. A required hardness is to be maintained during the high-speed machining of heat-treated material[11]. The range of hardness for a work material if lies between 40 and 65 HRC, then hard cutting tool insert is used for its machining, known as hard turning, a subtractive process[12].

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The unending urge for cutting the metals in an effective way has led the researchers towards the growth of new techniques for their machining process. The hard-to-machine materials have made hard turning significant over the grinding process as better surface finish of the parts along with the higher removal rate of the material is achievable. A huge positive response is claimed by the hard-turning process by defining new standards of quality machining[13]. Hard turning is associated with the better quality of surface for the workpiece along with the low wear of tool[14-16]. This process of Hard turning is beneficial against grinding process in the terms of production cost, productivity, efficiency, product quality and material properties, even when used with single or multilayer coated tool inserts. This process demands the right tool with high tool life for a work material in order to reduce power consumption. Presently the forthcoming demands of the manufacturing industries are superior cutting tool inserts for nearly all machining operations[17]. Ozel[18]concluded that cutting forces are dependent on cutting conditions and geometry of the cutting edges and workpiece hardness in hard turning[18]. It was inferred that work surface softens at high temperature while low cutting-edge radius yielded low radial and tangential force components. Hard coating for cutting tools are being extensively researched in past decades. The hardness of the coatings is now explicitly examined in terms of the range of coatings and their thickness varying from a few nanometres to a few millimetres. These help to enhance tool life as much as 10 times through a reduction in wear rate and further increase the productivity of the firm. Kupczyk[19]deduced coated WC-Co tool insert to be very efficient in numerous processes such as turning, milling, *etc*. The strength of the tool material lies in the refined grain structure along with enhanced mechanical properties[19]. Development of thin films through various coating deposition techniques has revolutionised the field of tool coating materials. Ferreira[20]discussed the ceramic and conventional tools on hard turned AISI H13 steel inferring that wiper ceramic tool are better in terms of the functioning of the tool[20]. Sahoo and Sahoo[21] investigated performance comparison between both TiN coated and ZrCN coated and uncoated carbide tool inserts yielding that coated surfaces perform better during the machining operations and among TiN and ZrCN coatings, TiN concluded better results[21]. Optimization was carried out by Kumar[22] for surface roughness, energy consumption during the machining process and material removal rate considering four input parameters *viz.* nose radius, cutting speed, depth of cut and feed rate through Taguchi approach. The model considered the effects of the interaction of the process parameters[22].

After the extensive research of the previous literature on turning and parametric optimization, it was observed that very few researcher[23] have found to be worked on the sliding and turning processes under the conditions of no lubrication while yielding the analogous results.The above literature study helped us in identifying the research gaps which were aimed for the fulfilment in the present research work in order to meet the demands of the manufacturing industries.

In the present work, we have analysed the tribological properties viz. tool wear, coefficient of friction (COF), and surface roughness, of WC tool. The aimof this work is to find out the optimal conditions for low coefficient of friction, good wear resistance and less surface roughness using a heuristic approach *i.e.* genetic algorithm (GA).WCtool inserts was selected for the pin material, keeping in mind the present application as tool inserts. The present study is relevant in exploring the opportunity of analysing the tribological results in comparison to the results obtained in machining process to achieve a lower coefficient of friction, lower loss of tool wear and lesser surface roughness. We have verified the same results practically by performing confirmation experiments on lathe machine for turning operation under the same experimental conditions.

2 Experiments details

2.1 Descriptions of disc and pin samples

The tribological behaviour of tungsten carbide pin against structural steel was investigated under dry sliding conditions in terms of friction, wear and surface roughness on a pin on disc test rig. This test rig is in accordance to ASTM International, formerly known as American Society for Testing and Materials, G99-04 standard[24,25]. Discs were prepared while following the Bureau of Indian Standards, IS: 2062. Disc has a diameter of 100mm. Discs had roughness of ranging from 0.15 to 0.45 μm and were secured to the disc holder which has a rotating axis with the help of a lock screw. Telly Surf was used to measure the Surface Roughness; at an interval of 45 8 reading were noted down in the radial direction and also from the middle of stroke 8 reading were taken.

Ambient temperature of 19°C to 21°C was maintained to perform the experiments under the dry conditions. These experiments were performed to record the wear of the tungsten carbide (WC) tool material along with the coefficient of friction. The cylindrical tungsten carbide pin samples were prepared with diameter 8 mm and length 70 mm for conducting tests on the prepared circular discs. The Pin on Disc test rig, tribological pairs, and all the accessories used for the experimentation are shown in Fig. 1[25].

The tests were performed at the sliding speeds of 2.4 m/s (144 m/ min) and 3.2 m/s (192 m/min) with variable disc track radius ranging from 40 mm to 80 mm. The selection of speed values was dependent on the range of the surface speed under the investigation. The tests were performed three times for recording the value of wear and coefficient of friction as well to have the average value[26-28].

2.2 Machining process

The selected work material for the experimental investigation was IS: 2062 specified steel. The hot rolled structural steels available in three grades, low, medium and high tensile strength. The sample was in the form of a solid rod which was tested for the identification of its chemical composition and the composition for the same is shown in Table 1. The dimensions of the workpiece used were 20 mm diameter and 200 mm in length. Cutting tools are designed with inserts or replaceable tips. We have used CNC tool inserts and these tools are known as indexable tools. In this experimental work, tungsten carbide tool bits were used during the turning process conforming to the "Turning Applications Manual of TaeguTec (Member IMC Group)". The experimental set-up of Lathe machine tool used for the machining process is shown in Fig. 2. The cutting parameters were selected for the turning operation on the Lathe Machine Tool for machining process(shown in Fig. 2). The value of selected parameters used is as follows:

Cutting velocity (V_c) = 100m/min, depth of cut (a_p) = 1mm, feed (f) = 0.12mm/rev and length of cut (L_c) = 25mm.

The EDAX was performed at the Nano Research Facility of Indian Institute Technology, Delhi. The obtained EDAX of the WC tool is shown in Fig. 3.

The composition of the tungsten carbide (WC) obtained from the EDAX shown in Fig. 3 is also depicted in Table 2. The weight % along with atomic % of the elements of WC is shown in Table 2. It is clearly visible that tungsten is present as 73.04 w % and carbide in the form of carbon as 20.046 w% (Table 2).

Table 1— Chemical composition of steel shaft (IS: 2062).

Element	Composition (%)
Iron	98.284
Carbon	0.213
Silicon	0.196
Manganese	0.760
Phosphorus	0.036
Sulfur	0.037
Chromium	0.161
Molybdenum	0.007
Nickel	0.094
Aluminium	0.032
Copper	0.169
Titanium	0.003
Vanadium	0.00

Fig. 1 — Experimentation set-up of used test rig (pin-on-disc).

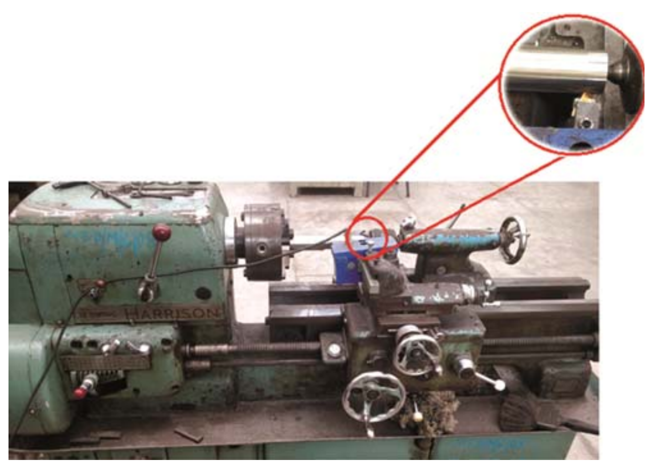

Fig. 2 — Experimental set-up of lathe machine tool for machining process.

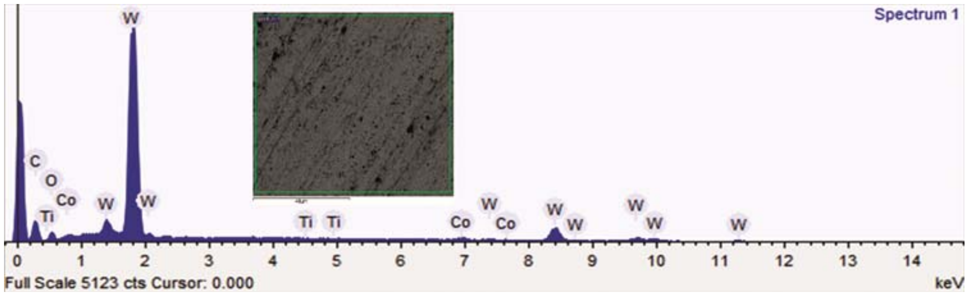

Fig. 3 — EDAX of tool material.

Table 2— Composition of the tungsten carbide tool.

Element	Weight %	Weight % σ	Atomic %
Carbon	20.046	0.605	68.817
Oxygen	5.307	0.443	13.677
Titanium	0.000	0.000	0.000
Cobalt	1.607	0.261	1.124
Tungsten	73.041	0.680	16.382

Microscopic image of WC tool bit was taken after the machining process and is shown in Fig. 4 (a) along with this a SEM image was also taken and is shown in Fig. 4 (b). These images show the wear developed on the WC tool inserts.

3 Results and Discussion

3.1 Optimization by genetic algorithm (GA)

Genetic Algorithm predictive model was considered for the optimization while, taking into account all the process parameters individually. Genetic Algorithm is one of the modern optimization techniques which is heuristic in nature. It creates the population through reproduction via three methods; selection, crossover and mutation. After setting the fixed parameters such as elite population, crossover function, mutated population *etc.* the optimized output parameters were yielded. The population count considered was 50 and the elite, as well as mutated population, was taken as 20% from the previous population. Through the M-file, the GA model was run for the considered output parameters *viz.* coefficient of friction, surface roughness (SR)and tool wear[28,29]. These parameters have been discussed in section 3.2. Also, the experimentation on pin-on-disc test rig yielded results considering individual parameters. This helped in building a similar comparison of turning and tribological tests.The experimental investigation was in relevance to researches conducted in the past. Similar work was carried out by Rech[30] in 2018 and Mishra[23] in 2019.

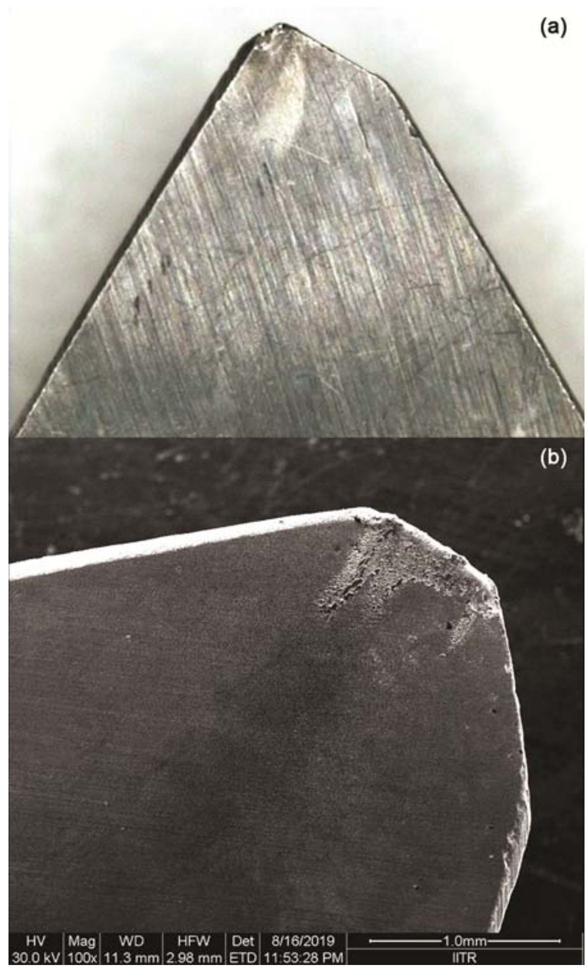

Fig. 4 — (a) Microscopic image of crater wear of WC insert during turning process and (b) SEM image of crater wear of WC insert during turning process.

3.2 Development of genetic algorithm's predictive model

The wear, coefficient of friction and surface roughness were expressed in terms of diameter, load and speed. The response function in the general form can also be expressed as the following:

$$Y = \emptyset(V, L, D) \quad \ldots (1)$$

where Y = Response (tool wear/coefficient of friction/surface roughness); V = Cutting speed (m/min); L = Load applied (N); D = Diameter (mm)

Using the following regression equation

$$Y = \beta_0 + \beta_1 V + \beta_2 L + \beta_3 D \quad \dots (2)$$

where β_0 is constant while β_1, β_2, and β_3 are partial regression coefficients of the model from which the response function was generated as given below:

$$TW = C_1 \ V^{\times 1} L^{\times 2} D^{\times 3} \quad \dots (3)$$

$$COF = C_2 \ V^{\times 1} L^{\times 2} D^{\times 3} \quad \dots (4)$$

$$SR = C_3 \ V^{\times 1} L^{\times 2} D^{\times 3} \quad \dots (5)$$

where TW= Tool wear; COF = Coefficient of friction; SR = Surface roughness

C_1, C_2, C_3 = Constant

V = Cutting speed (m/min)

L = Load applied (Kg)

D = Diameter (mm)

The unknown coefficients, namely, exponents of cutting speed, load applied and diameter and constants involved in above equations were determined by minimizing the least squares error between experimental and predicted results obtained within the range of cutting conditions.

3.2.1 Tool wear

Equation (2) developed in section 3.2 using regression analysis for the output parameter 'tool wear' is given as:

$$Wear = 0.20 - 0.363\,Diameter + 0.039\,Load + 1.13\,Speed \quad \dots (6)$$

The predictive equation number (3) developed for the optimization model is used for optimizing the Tool Wear and is given as:

$$Tool\_Wear = 1.221 \ \times (1)^\wedge(-0.363) \ \times (2)^{0.039} \ \times (3)^{1.13} \quad \dots (7)$$

After setting the fixed parameters the optimized output parameter was yielded which was 3.71088 µm, as it is evident in Fig. 5. The population count considered was 50 and the elite, as well as mutated population, was taken as 20% from the previous population. The optimized value of tool wear was obtained at a sliding speed of 3.2 m/min, a load of 20.085 Kg and diameter of 3.502 mm.

3.2.2 Coefficient of friction

Equation (2) developed in section 3.2 using regression analysis for the output parameter 'Coefficient of Friction' is given as:

$$COF = -0.78 - 0.054\,Diameter + 0.0272\,Load - 0.510\,Speed \quad \dots (8)$$

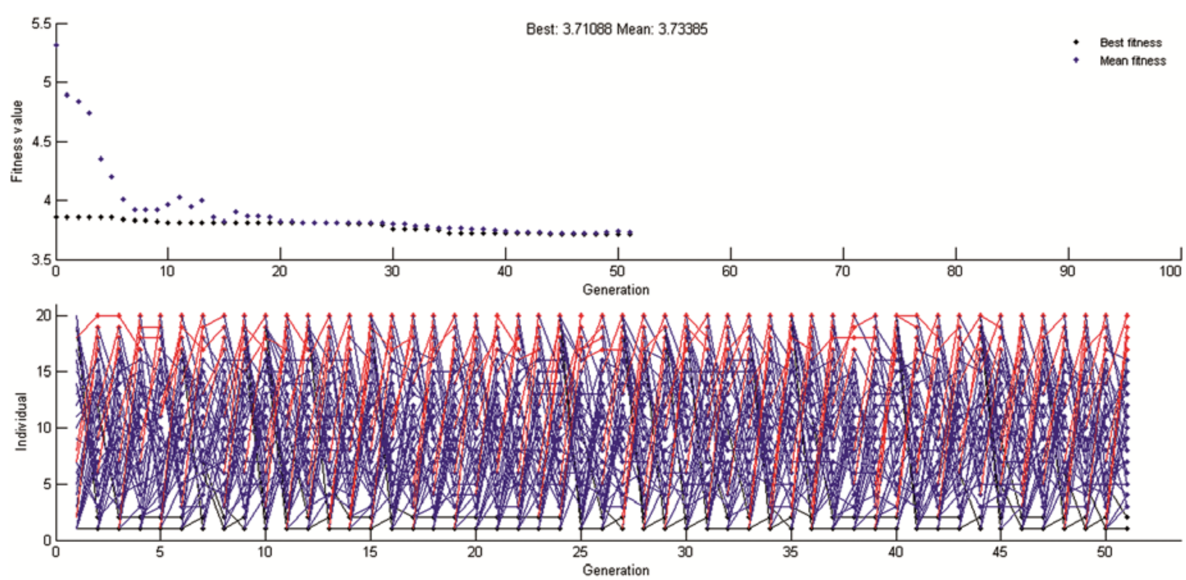

Fig. 5 — GA graph for tool wear.

The predictive Eq. (4) developed for the optimization model is used for optimizing the coefficient of friction is given as:

$$Coefficient\_of\_Friction = 0.458 \times (1)^\wedge(-0.054) \times (2)^\wedge(0.0272) \times (3)^\wedge(-0.51) \quad \ldots (9)$$

During the optimization process, the optimized coefficient of friction was yielded as 0.195706. This obtained value is also shown in Fig. 6. This optimized value of the coefficient of friction was obtained at sliding speed of 3.1.99 m/min, a load of 20.349 Kg and a diameter of 5.5 mm.

3.2.3 Surface roughness

Equation (2) developed in section 3.2 using regression analysis for the output parameter 'Surface Roughness' is given as:

$$SR = -2.57 + 0.022\, Diameter + 0.0036\, Load + 0.321\, Speed \quad \ldots (10)$$

The predictive Eq. (5) developed for the optimization model is used for optimizing the surface roughness and is as follows:

The predictive equation developed for the optimization model is:

$$Surface\_Roughness = 0.0765 \times (1)^\wedge(0.022) \times (2)^\wedge(0.0036) \times (3)^\wedge(0.321) \quad \ldots (11)$$

During the optimization process, the optimized value of SR was obtained as 0.117857 µm, as can be seen in the Fig. 7. This optimized value was obtained at a sliding speed of 2.4 m/min, a load of 20 Kg and a diameter of 3.5 mm.

4 Confirmatory experiments

A set of confirmatory experiments are done for checking the optimality of the obtained results[31]. The optimum levels of the defined parameters were set and analysation of the output variables were done. It was inferred that the tool wear was optimum when the machining parameters were set in accordance with the experimental conditions of the pin-on-disc test rig. The confirmation experiments were conducted at the optimum setting of the process parameters which yielded optimum tool wear, coefficient of friction and surface roughness. The sliding speed was 3.2 m/min, load at 20.085 Kg and diameter of 3.502 mm was used for performing the confirmation experiment to obtain optimal tool wear. Similarly, the sliding speed was 3.199 m/min, load at 20.035 Kg and diameter of 5.5 mm was used to obtain optimal coefficient of friction and for obtaining the optimal value of Surface Roughness the sliding speed was 2.4 m/min, load at

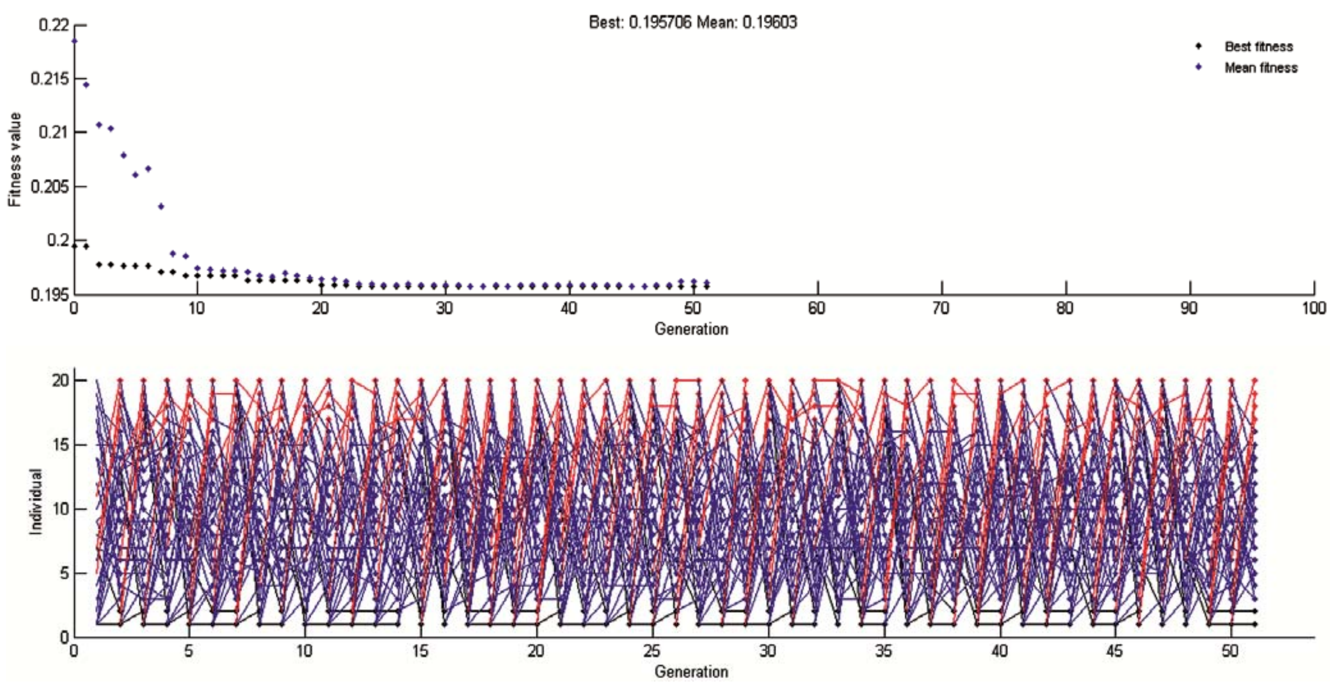

Fig. 6 — GA graph for coefficient of friction.

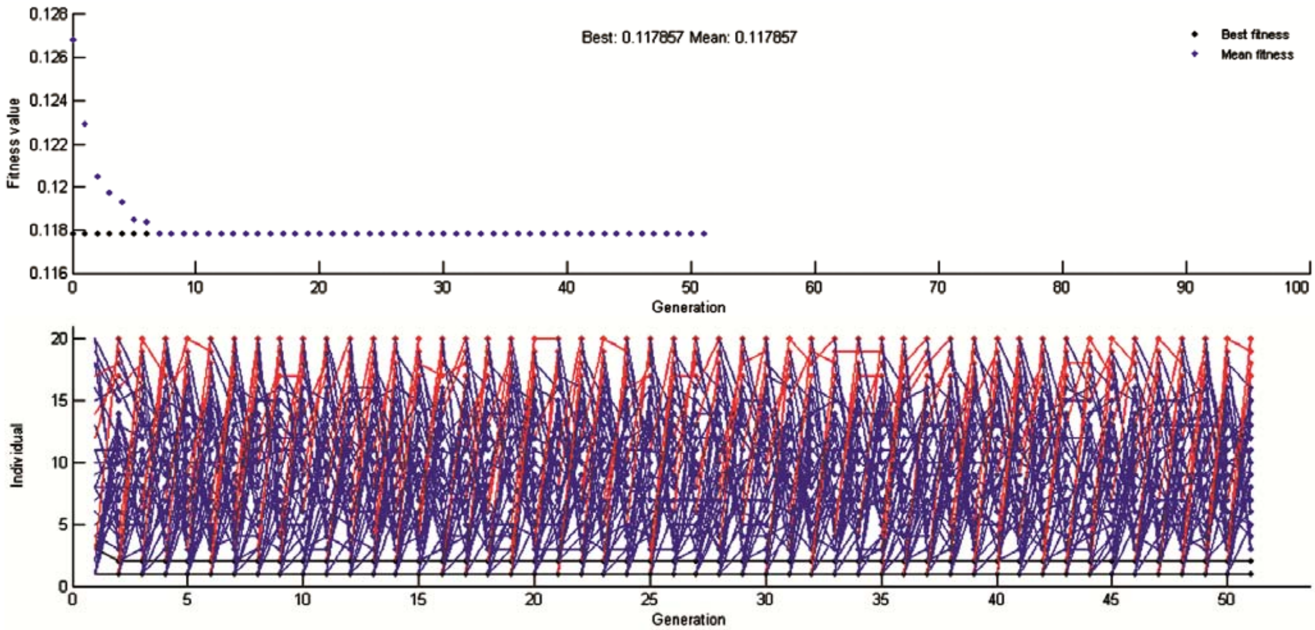

Fig. 7— GA graph for surface roughness.

20 Kg and diameter of 3.5 mm. The results obtained after conducting the confirmation experiments have been discussed.

5 Conclusions

An attempt was made to analyse the cutting tool wear by means of an experimental investigation on the pin-on-disc test rig. The material of the stationary pin was analogous to the material of cutting tool while the disc material was the same as work material. The tribometer was used to simulate the tribological behaviour, which were compared with the tool wear values obtained during the turning process on the lathe machine tool. The attempt to validate the results obtained from experiments on tribometer was carried out by performing similar experiments on lathe machine tool under similar experimental conditions. The results were within the tolerance limits.

(i) The optimized value of tool wear was obtained at a sliding speed of 3.2 m/min, a load of 20.085 Kg and diameter of 3.502 mm.

(ii) The optimized coefficient of friction was yielded as 0.195706 and this optimized value of the coefficient of friction was obtained at sliding speed of 3.1.99 m/min, a load of 20.349 Kg and a diameter of 5.5 mm.

(iii) The optimized value of SR was obtained as 0.117857 µm. This optimized value was obtained at a sliding speed of 2.4 m/min, a load of 20 Kg and a diameter of 3.5 mm.

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References

1 Zhang P & Liu Z, *J Clean Prod*, 161 (2017) 676.
2 Krolczyk GM, Nieslony P, Maruda RW & Wojciechowski S, *J Clean Prod*, 142 (2017) 3343.
3 Maruda RW, Krolczyk GM, Michalski M, Nieslony P &Wojciechowski S, *J Mater Eng Perform*, 26 (2017) 431.
4 Park KH, Yang GD, Suhaimi MA, Lee DY, Kim Tae-Gon, Kim Dong-Won & Lee, Seok-Woo, *J Mech Sci Technol*, 29 (2015) 5121.
5 Maruda RW, Krolczyk GM, Wojciechowski S, Zak K, Habrat W & Nieslony P, *J Mech Sci Technol*, 32 (2018) 1585.
6 Kaynak Y, Karaca HE, Noebe RD & Jawahir I S, *Wear*, 306 (2013) 51.
7 Krolczyk GM, Maruda RW, Krolczyk JB, Nieslony P, Wojciechowski S & Legutko S, *Measurement*, 121(2018) 225.
8 Klocke F &Eisenblätter G, *CIRP Ann*, 46 (1997) 519.
9 Noordin MY, Venkatesh VC & Sharif S, *J Mater Process Technol*, 185 (2007) 83.
10 Chinchanikar S & Choudhury S K, *Measurement*, 55 (2014) 536.
11 Mia M, Rifat A, Tanvir M F, Gupta M K, Hossain M J & Goswami A, *Measurement*, 129 (2018) 156.

12 Mia M, Razi MH, Ahmad I, Mostafa R, Rahman SMS, Ahmed DH, Dey PR & Dhar NR, *Int J Adv Manuf Technol*, 9 (2017) 3211.
13 Dogra M, Sharma V S, Sachdeva A, Suri N M & Dureja J S, *Int J Adv Manuf Technol*, 57 (2011) 541.
14 Dobrzański LA, Pakuła D & Hajduczek E, *J Mater Process Technol*, 157 (2004) 331.
15 Ichijo K, Hasegawa H, & Suzuki T, *Surf Coatings Technol*, 201(2007) 5477.
16 Faga M G, Gautier G, Calzavarini R, Perucca M, Boot E A, Cartasegna F & Settineri, L, *Wear*, 263 (2007) 1306.
17 Rana R, Rajput K, Saini R & Lal R, *Int J of Mod Eng Res*, 4 (2014) 35.
18 Ozel T, Hsu TK & Zeren E, *Int J Adv Manuf Technol*, 25 (2005) 262.
19 Kupczyk M J & Komolka J, *Int J Refract Met Hard Mater*, 49 (2015) 225.
20 Ferreira R, Řehoř J, Lauro CH, Carou D & Davim J P, *J Brazilian Soc Mech Sci Eng*, 38 (2016) 2413.
21 Sahoo A K & Sahoo B, *Measurement*, 45 (2012) 2153.
22 Kumar R, Bilga P S & Singh S, *J Clean Prod*, 164 (2017) 45.
23 Mishra S K, Ghosh S & Aravindan S, *Wear*, 428 (2019) 93.
24 Lal R & Singh R C, *World J Eng*, 16 (2019) 560.
25 Lal R & Singh R C, *Surf Topogr: Metrol Prop*, 6 (2018) 035001.
26 Singh R C, Pandey R K, Lal Roop, Ranganath M S & Maji S, *Surf Topogr Metrol Prop*, 4 (2016) 034005.
27 Lata S, Rana R & Hitesh, *Mater Today Proc*, 5 (2018) 4250.
28 Rana R, Walia R S & Lata S, *Mater Today Proc*, 5 (2018) 3936.
29 Rana R, Murtaza Q & Walia R S, *World J Eng*, 17 (2020) 335.
30 Rech J, Giovenco A, Courbon C & Cabanettes F, *CIRP Ann*, 67 (2018) 65.
31 Rana R, Walia RS, Qasim Murtaza & Tyagi Mohit, *AES-ATEMA 29th Int Conf*, July (2016) 151.