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Machinability of Bearing Steels by Face Turning Method

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Abstract—The present paper is an attempt of an experimental investigation on the machinability of bearing steels by face turning method. The research work findings here provides useful economic machining solution to fulfill the local objectives of knowing, in advance, the machinability of selected bearing steels by a simple, easy and effective face turning method.The face turning method makes use of cylindrical ring shaped steel specimen as test pieces for testing the machinability of the steels. Two similar bearing grade steel material but with slightly different in chemical composition has been undertaken for the purpose of machinability studies by face turning method. The critical number of cutting passes up to flank wear of 0.3mm, tool wear development, surface finish and morphology of the chips were the criteria for checking technical effectivity of the face turning method. The tests are being carried according to the guidelines laid in the international standard ISO 3685:1993E, tool life testing with single point turning tools. The results presented here demonstrate the ability of the face turning method to differentiate the machinability of two bearing steels having a slight change in their chemical compositon .

Index Terms— Bearing steels, Face turning, Machinability.

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1 INTRODUCTION

THE engineering industries strive to achieve either a minimum cost of production or a maximum production rate in machining. These two criteria are difficult to meet in today's competitive manufacturing environment. Approximately 75% of the manufacturing activities in the industrialized countries deal with production of a small batch size with a large variety of products which are diverse in nature [18]. Thus it is becsoming increasingly necessary to relate the available engineering raw materials and semi-finished products to specify machinability ratings. It is advantageous for the industries to know in advance behavior of wear and life of tool with respect of specific steel grades which needs to be processed along with chemical composition and mechanical data, which by themselves is not enough to cover the machining characteristics of the material.

There are two basic types of tests to determine machinability studies of steels – long term and short term test [1]. The main drawback in long term test is that the tools require a fairly long time before reaching the stipulated wear limit. Moreover the long term test is possible only in the industries with research and development centres. Adequate recording of industrial experience is essential. E.M.Trent and Paul Wright [2] reported that such tests are apt to be expensive in material and manpower, not least because of the large scatter in individual test results. This work involves very careful measurement of the very small amounts of wear, the use of a microscope being essential. Judgment is required by the investigator on what is significant and what can safely be ignored.Such tests are beyond the reach of small and medium industries who are working with four to five grades or large variety of commercially available steels. Thus the efforts to minimize consumption of the material and to save time on the long tests have led to the development of short time tests. Face turning operation is one of the short time test taken as method to test the machinability of the steels. This can be conveniently done with minimum amount of resources. A.Salak et al. [3] have successfully demonstrated the face turning method for assessing machinability of five different types of powder metallurgy steels. Flank wear, V_b of 0.3mm was taken as tool life criterion. Karin Bjorkeborn et al.[4] recommended the Volvo Standard Machinability Test as a potential method for assessing machinability of materials. A common case hardening steel, 20MnCrS5 was chosen here for investigations. With suitable altered heat treatment four varieties of microstructures of the same steel were obtained. The Volvo test makes it possible to rank material by tool wear with relatively small samples and low material volumes. The authors stated that approximately 800 mm length of bar and 50 mm in diameter is needed for testing a material and the other traditional test with respect to toolwear are more costly to perform, both in time and material consumption. E.M.Trent and Paul Wright [2] reported tool testing standards set by F.W.Taylor. These tests were all carried out by lathe turning of very large steel billets using single point tool. Such elaborate tests have been too expensive in time and manpower to repeat frequently, and it has become customary to use standardized conditions, with cutting speed and feed as the only variables. The results are presented using what is called Taylor's equation, which is Taylor's original relationship reduced to its simplest form

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$$V T^n = C \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where V = cutting speed, T = cutting time to produce a standard amount of flank wear and C and n are empirical constants for the material or conditions used.

There is no published data regarding the face turning as a method to test machinability of bearing steels. The aim of this work is to test the machinability of the most commercially and locally used bearing steel grades which are slightly different in chemical composition by a short time face turning test method.

2 Experimental Procedure

2.1 Face turning method

The principle of this method is shown on figure1.In this test, face turning of cylindrical standard steel bars is done from the surface of the centre of the hole, ø6mm, to the circumference of the cylindrical products at constant workpiece revolutions, feed and depth of cut. After finishing the first pass, a second face turning from the center of the hole follows. The consecutive passes are repeated up to the critical flank wear (V_b) is reached to 0.3mm. This face turning test enables determining Taylor's relationship as in equation (1).This test method can represent more accurately modern production which often involves short series including mixed cutting cycles and operation. At such stage, a conventional longitudinal operation involving a large number of short (compared to total tool life) cutting and non-cutting cycles was defined by the terminology 'interrupted machining mode,(IMM)[5].This is in reality the case of this face turning method using workpieces where cut is interrupted after arriving at the outer diameter with repeated tool entry. For very short cycles below the critical time, as can be the case in this method, the tool wear can exceed the corresponding wear in continuous machining. This method can occasionally give a positive result, as interruption appears to facilitate the cooling of the tool and lowers the average temperature of tool giving real tool life.

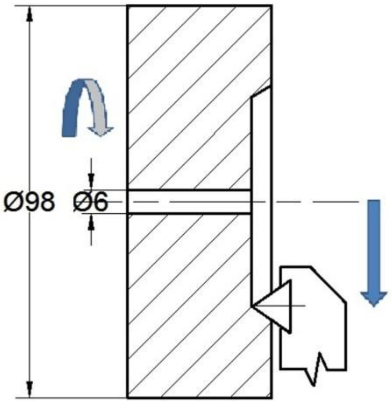

Fig. 1. Principle of face turning method

The process parameters are chosen so as to promote rapid tool wear at minimum material removal. The cutting speed for workpiece grade is chosen because of its industrial relevance and are bit higher than the optimum value according to Makarovs' law, " minimum tool wear occurs at the optimum cutting speed" [6].In general the cutting speed is so selected that the tool life at the highest speed is not less than five minutes [7].The depth of cut of 0.4mm chosen is enough to get flank wear land with minimum consumption of work material. The feed rate chosen was 0.145mm. Research works have shown that the temperature of the tool is highly affected by the cutting speed than the depth of cut and the feed rate [20]. Further the work material bar diameter of 100mm chosen was also on higher side to aggravate the tool wear .F. Baud [8] investigated that the bar diameter has an influence on the tool temperature and, by implication, on tool wear. The tests are being carried according to guidelines laid in the international standard ISO 3685:1993E [7], tool life testing with single point turning tools.

2.2 Workpiece material

The workmaterial used here is a standard bearing steel having an equivalent grade of America and Britain as SAE/AISI 52100 and EN31 respectively. Their chemical composition is shown in table 1. The hot rolled workpiece of ø100mm was premachined to ø98mm to remove hard scales, hot rolled skin and unevenness on the peripheral and end surface of the as received material. The premachining work also ensures proper cylindricity, concentricity and run-out to prevent vibration. Then a drill of ø6 mm was made at the center along the axis of the work material to facilitate the entry of the tool at the beginning of every pass. Chemical composition of each work material was determined over the cross-section and average values were obtained as shown in table 1.Since there is a slight change in chemical composition of these two bearing steels, it will be known as Sample-I and Sample-II henceforth throughout the discussion in this paper. Before conducting the experiments the hardness of all the workpieces over the complete cross-section was determined. The hardness of Sample-I and Sample-II are 198 and 218 HB respectively. The hardness' were within the limits of ± 5% over complete cross section of the workpiece.

Table 1
Chemical Composition in % weight

Bearing Materials	C	Si	Mn	P	S	Cr	Fe
Sample-I	1.12	0.26	0.48	0.06	0.05	1.1	96.76
Sample-II	1.19	0.34	0.53	0.05	0.05	1.49	96.00

2.3 Tool Material

A hard metal P-30, triangular uncoated, carbide insert is used for cutting the above workpiece material with a general purpose ISO tool holder CTLPR2020L16. The hardness of tool insert is 88 HRA.

2.4 Face turning conditions

Dry face turning was conducted under the following condition- feed, 0.145 mm/rev; depth of cut, 0.4mm and constant revolution of 796 rpm of lathe spindle.

3 RESULTS AND DISCUSSIONS

3.1Tool wear development

The experimental investigations suggest that for hard material crater wear rate is influenced by both cutting speed and feed rate, while flank wear rate seemed to be mainly effected by cutting speed. When the crater wear is present the wear mechanisms are abrasion, deeply affected by cutting speed and the diffusion is heavily influenced by the cutting temperature. On the other hand the flank wear mechanism is mainly due to abrasive phenomena strongly affected by cutting speed [12].Research works have shown that temperature of the tool is highly affected by the cutting speed than the depth of cut and the feed rate [20].

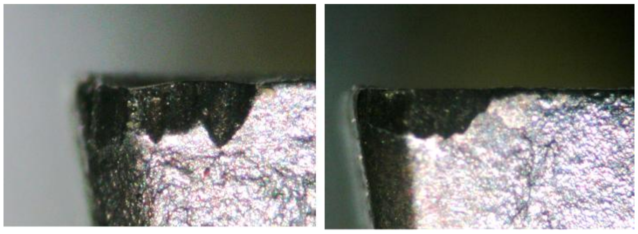

Fig. 2. Flank wear images of carbide inserts after machining (a) Sample-I (b) Sample-II steels.

The contributing factor to the differences in flank wear rates of all the material could be the hardness of the workmaterial. In general harder work material will result in higher cutting stresses and tool temperature, leading to greater tool wear. However, the hardness of the steel may not be the only variable affecting the flank wear. The composition and microstructure of the steels are likely to be important [13].

In both the steels, abrasive wear is dominant. The hard particles abrade and remove material from the tool. The flank images of tool insert are shown in fig (2). It can be observed that the wear in flank and crater at the beginning stages is mainly due to abrasion and then diffusion wear occurs which is influenced by cutting temperature at higher speeds. Thermal cracks are observed on the tool due to the speeds as high as 245 m/min. This is the result from cyclic loading of the tool in interrupted cutting or when machining materials which generate high tool-chip temperature.

3.2 Machinability of steels

Fig. 3 shows the relationships between tool wear growth up to V_b = 0.3mm and the number of passes performed. The results show the sensitivity of the applied face turning test method to the slight variation in the chemical composition of the two steels used. The effect of the differences in carbon, manganese and chromium content of the test samples on the machinability was clearly revealed by the chosen test. Sample-I showed better machinability than Sample-II .Fig. 3 shows the critical cutting time, i.e the cutting time for which the tested steel could be machined until the critical wear V_b = 0.3mm was attained. The total cutting time for testing excluding idle time is 24.7 min. This result justifies to call the test method as a short time method.

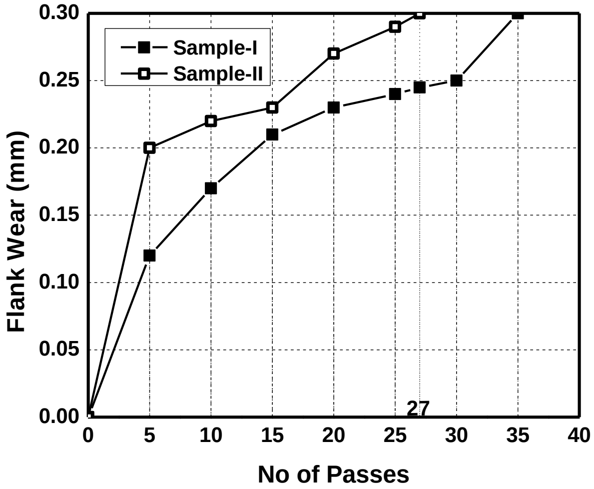

Fig. 3. Relationship between the critical number of passes and critical flank wear

3.3 Surface finish

For assessing the possible effect of the carbon and chromium composition on mechanical properties of the specimen, the roughness of the machined surface was taken both as mean value of the highest roughness peak Rz and the mean arithmetic deviation of the roughness Ra. The results are shown in the table 2. The highest roughness was exhibited by the Sample-II. The roughness of a machined surface is a result of interaction of the workpiece properties and the tool material and the geometry under the cutting condition used. Sample-I showed better finish than Sample-II.

TABLE 2
SURFACE ROUGHNESS[Ra and Rz in µm] VALUES TAKEN AFTER EVERY FIVE PASSES AND AT THE END OF TOOL LIFE

Bearing Materials					
No. of passes	Sample-I		No. of passes	Sample-II	
	Ra	**Rz**		**Ra**	**Rz**
5	2.30	13.41	**5**	4.36	17.43
10	4.07	20.29	**10**	4.20	15.28
15	5.65	23.79	**15**	5.01	21.71
20	6.58	26.84	**20**	6.65	26.48
25	6.92	27.33	**25**	7.82	29.08
30	8.07	32.34	**27**	7.99	29.48
35	8.44	32.92			

The results prove the influence of the base workpiece properties on the roughness as well as the suitability of the cutting method used in defining the machinability via surface finish Fig.5 shows SEM images of the machined surfaces after the tool inserts have reached the tool life criteria of 0.3 for after machining the workmaterial Sample-I and Sample-II respectively. From the images it is very evident that the for Sample-II the tool marks are dominant. The workpiece being hard has abraded the tool giving rise to newer edge frequently. The newer tool edge in turn has given rise to higher surface roughness value after every new pass. This is clear from the increasing surface roughness values obtained in the table 2 and fig. (3) for Sample-II steel material. Thus the tool wear for machining Sample-II steel material is mainly due to abrasion. Whereas the tool wear in Sample-I steel material is both, first due to abrasion and then due to adhesion. This investigations from SEM also depicts the sensitivity of face turning test method.

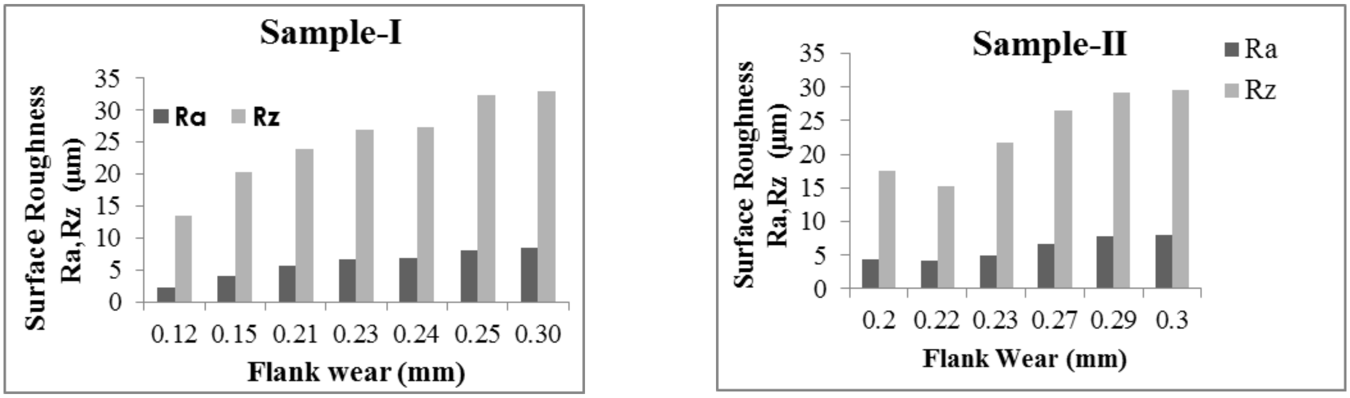

Fig. 4 Surface Finish Ra and Rz at every five passes for Sample-I and Sample-II

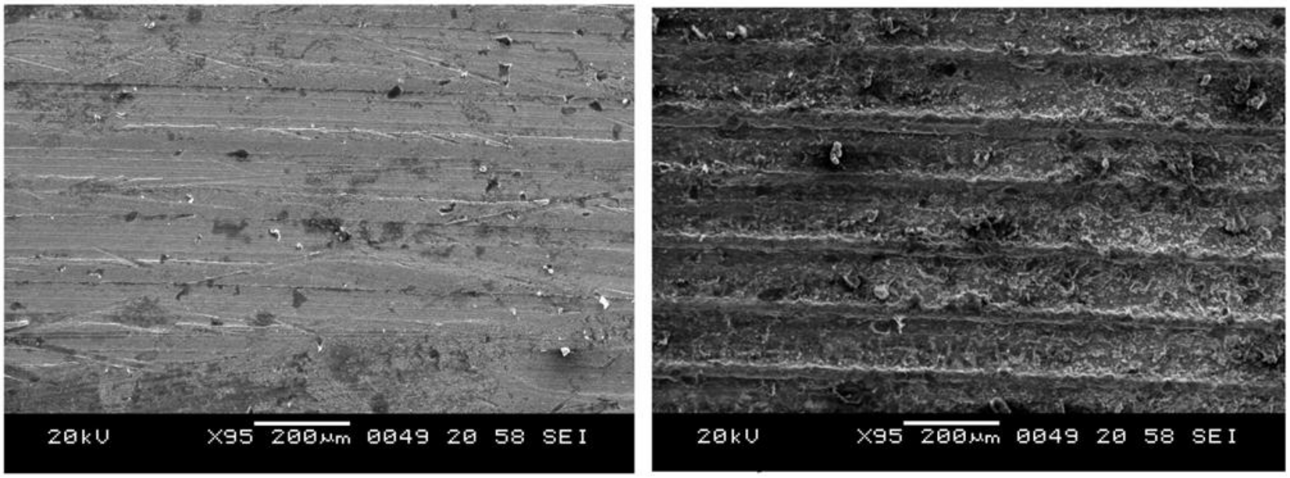

Fig. 5. Machined surface images, SEM, after face turning of (a) Sample-I and (b) Sample-II

3.4 Chip Morphology

The morphology of the chips formed when face turning the specimens was affected by the base alloy composition. The chips are as shown in the fig. (6) a and b.

Fig.6 (a) shows the chips of Sample-I which are blue colored elemental arched of uniform sizes of about 3 to 5 mm.

Fig.6 (b) shows the chip of Sample-II which are discontinuous tubular.

The colored chips proved that the temperature in the cutting zone is high. The morphology of the chips formed in machining depends on the work piece properties and on the cutting conditions. The different morphologies of the chips shown here confirms the sensitivity of the test method used.

Fig. 6. Chips of (a) Sample-I and (b) Sample-II

4 CONCLUSIONS

The following results are presented from the experimental study.

- The Face turning method presented here for evaluating the machinability studies of bearing steels represent the contemporary machining involving interrupted cuts.
- Development of tool wear for the two workmaterials is in line with traditional machining methods.
- The machinability of Sample-I is better than Sample-II.
- The face turning method demonstrated good sensitivity even for slight change in the percentage of chemical compositions of carbon, manganese, and chromium in bearing steels.
- The cutting time for testing these two specimen was hardly 25 min which justifies this method as short time method.
- The face turning method is easy and simple. It fulfills many of the criteria for the characterization of the machinability for the given cutting conditions.

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