A COMPARATIVE STUDY OF THE MACHINING ECONOMY IN TURNING AND GRINDING OF COLD METAL SPRAYED SURFACES

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ABSTRACT

The procurement of spare parts is considered to be the main problem affecting the maintenance of both military and civilian equipment. Many attempts have been done to manufacture some spare parts locally in order to avoid importation, while other attempts have been done for the renewal of spare parts which can neither be manufactured nor imported. The process of coating spare parts with protective coatings is one of the most important methods for renewal. This method is used for renewal of spare parts of railway, agricultural, industrial and some of military equipment such as vehicles and tanks. The spare parts are sprayed with hard diffused metallic powders (basically chromium carbides) which make a hard layer. Owing to the excessively high hardness of the coated layer, grinding is the known process used for machining such a layer which leads to considerably long machining time and hence high cost of spare parts renewal. The aim of present work is to study the possibility for the replacement of grinding by turning using modern tool materials such as aluminum, oxinitride coated carbide (ALON)- grade HK-15 and cubic boron nitride (CBN)[1] to reduce machining time and cost of coated spare parts. A computerized measuring system was developed to enable the on line measurement of the three components of the cutting force, and the cutting temperature. Machinability tests have been carried out using the above mentioned tool materials to determined the machinability parameters necessary to calculate the optimum cutting conditions in turning of the protective coating.

INTRODUCTION

Rotating and sliding parts are always subjected to wear and after some time they must be replaced. The procurement of the needed spare parts is rather expensive and time consuming. At present the damaged portions of shafts are repaired by electric arc surfacing, electrospark alloying, galvanic chrome plating, pressing on of a sleeve, etc. These methods are laborious and in many cases do not provide the necessary quality of repaired parts.

A low-powder, flame spray technique known as Rotectec cold process has been developed, in a which a standard Oxygen and Acetylene fuel supply is used, and can be applied to Ferrous materials as well as Aluminum and Copper base alloys. The maximum temperatures during Rotatic coating can be kept as low as 200 °C, giving the advantage that for shafts with critical tolerances, distortion is minimal [1]. The rotatic process has been designed to produce wear resistant coatings which will increase the service life of essential machine parts. It can be used for rebuilding fine edges, medium size surfaces and for the coating of very large parts [2].

The most important problem encountered in machining the coated in machining the coated parts is the proper selection of the cutting tools. Improved tool materials have greater potential for reducing greater potential for reducing machining costs than any reducing machining costs than any other single variable. The optimum choice and application of modern tools are the key to major economic benefits in terms of reduced production costs [3].

Tools coated with hard materials have special importance in the field of machining. The type of the machining operation and the workpiece material play a decisive role in selecting the optimum grades of the coating carbides. Coated carbide tool were found to have outstanding wear resistance in high speed turning, in

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[1] - KH-15 and CBN cutting tools are produced by widia Krupp Co.

addition, the quality of the surface machined (surface integrity) with these tool was found to be better than that with other tools [4]. Another tools material which can be used for machining hard materials is the CBN. Which can be used for turning ferrous materials having hardness values exceeding 50 HRc. The machining of hardened steel components by this means may be considered as a substitute of cylindrical grinding in many instances. In certain cases, for example, when large cylindrically shaped components with relatively large step reductions in diameter have to be machined, turning by means of CBN tools may prove particularlt successful. Generally surface roughness values better than 0.6 μm (Ra) can be obtained when turning hardened stell components by means of CBN tools [5].

Coadted carbides and CBN can be used in turning instead of grinding which reduces the manufacturing cost [6,7] but the selection of the optimum values of cut based on the minimum production cost or maximum production rate may considered as significant factor encourag-coated use of CBN and HK-15 than grinding.

The determination of the optimum values of cut implies the determination of the most important machinability indices to satisfy both quality and cost objectives. Often, experimental determination of the machinability criteria are used for the comparative evaluation of different workpieces or tool materials [8]. To get reliable machinability data, comprehensive information about the material behavior under the whole ranges of cutting variables must be obtained. This requires a series of carefully designed machinability tests that must be carried out for each type of tool material Tipnis et al, in 1978, [9] refused the idea of "General purpose machinability testing" that is carrying out all the possible machinability tests such as tool life, cutting forces and power tests, temperature tests, dynamic tests, surface roughness tests, ... etc. Instead, he suggested that only some of the machinability tests are to be selected and performed based on the purpose.

Up till now the metal sprayed surfaces are machined by grinding, which increases considerably the machining time and cost of spare parts. The development of modern cutting tool materials such as ALON multi layer coated carbide and CBN tools, often the possibility to machine the sprayed spare parts by finish turning.

The aim of the present work is to investigate the posssibility of the replacement of grinding by turning using modern tool materials such as Aluminum, oxinitride coated carbide ALON grade HK-15 and cubic boron nitride (CBN) to reduce the machining time and cost of the nenewal process.

EXPERIMENTAL TECHNIQUES

The main object of the experiments carried out in the present investigation is to study and to determine the machinability data of the coated workpiece material using Cubic Boron-nitride (CBN) and multi layer coated carbide (HK-15) tool materials. The experiments included the measurements of the cutting forces, cutting temperature, tool life and surface roughness so as to obtain the empirical relationship required for the description of the cutting process and hence for the optimization of the machining variables. Experiments were carried out in dry cutting. The experimental work was carried out on a center lathe on which the test rig was mounted.

prepartation of the test workpieces

The workpieces used in tests are as shown in Figure (1), the workpieces were coated with Durotec,19910, employing the Rototec cold coating method. An oxyacetylene flame was used to spray the metal in a layer of 3 mm thick. Table (1) shows the chemical composition of the used workpieces.

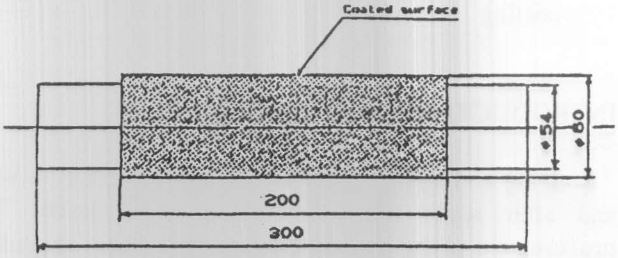

Figure 1. The workpiece under test.

Table 1. Chemical composition of the workpiece material.

Chemical composition					
AL%	SI%	CR%	Fe%	NI%	HCR
2.17	9.61	16.78	3.80	24.01	48

Test righ used for cutting force and cutting temperature measurements

The used test rig is shown in Figure (2), which consists of a standard 3-components dynamo-meter arranged to measure the cutting temperature and the cutting force components simultaneously. The output signals of the dynamometer (The cutting forces and the cutting temperature) are sent to specially designed low pass filters and DC amplifiers (consisting the data acquisition system to measure and amplify the static cutting force component signals.

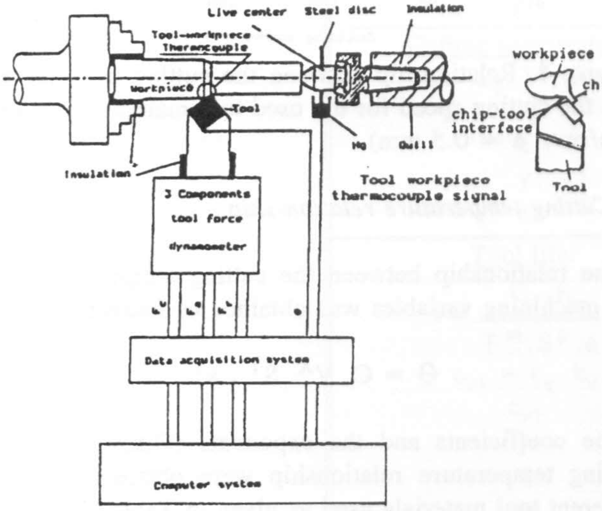

Figure 2. the used test rig.

The amplified signals are sent to the computer system via an interface which incorporates a high performance 16-channel analog-to-digital converter for data collection controlled by a specially prepared software. The on line measurement of the cutting force and the cutting temperature using the computer system enabled fast readout of these quantities and hence resulted in a considerable saving of the consumption of the expensive workpiece and tool materials. The test rig was calibrated before and dring the tests. The calibration factors were entered to the computer program to transfor the measured values into force and temperature units.

Measurement of tool wear (Flank wear land) B

In order to obtain a sufficient - information about the wear - time characteristics for the used tool materials with the workpiece under test, many tests have been carried out at different cutting conditions.

The flank wear land width B was measured using tool room microscope with magnification (* 20). The flank wear was measured from six to ten times at each cutting conditions till the flank wear exceeded 0.4 mm

Tool life

maximum value of the flank wear land of 0.3 mm was taken as a tool life criterion for both HK-15 and CBN tools tips, at which the relationship between the tool life and the different cutting conditions were obtained.

Surface roughness tests

Surface roughness tests were carried out using Surtronic 3 surface measurement. The roughness height (R) was evaluated as the average of five measured peak to valley values from the records. The measurements were done along the length of the workpiece.

EXPERIMENTAL RESULTS AND DISCUSSION

The effect of the machining variables (V, S and a) on the basic machining quantities were obtained for the used tool materials and discussed as follows:

1- Cutting forces:

The effect of the cutting speed on the cutting forces can be explained by its effect on the frictional conditions at the chip-tool interface. it can be seen that the cutting forces in case of HK-15 are larger than those obtained in the case of CBN due to the higher hardness of the latter, which reduces the coefficient of friction and hence the cutting forces. Figure (3) shows the effect of the tool material on the cutting forces.

Empirical formula for the calculation of the cutting force components

The following formulae have found the widest application for the calculation of the cutting force components

$$F_c = K_{sc}.\ S^{X1}.\ a^{Y1}$$

$$F_a = K_{sa}.\ S^{X1}.\ a^{Y1}$$

$$F_r = K_{sr}.\ S^{X1}.\ a^{Y1}$$

Where:

K_{sc}, K_{sa} and K_{sr} are the specific cutting pressures for the cutting force components: F_c, F_a and F_r respectively.x1 and y1 are the exponents of the feed and the depth of cut respectively. The coefficients and exponents of the formulae were determined for the different used tool materials as given in Table (2).

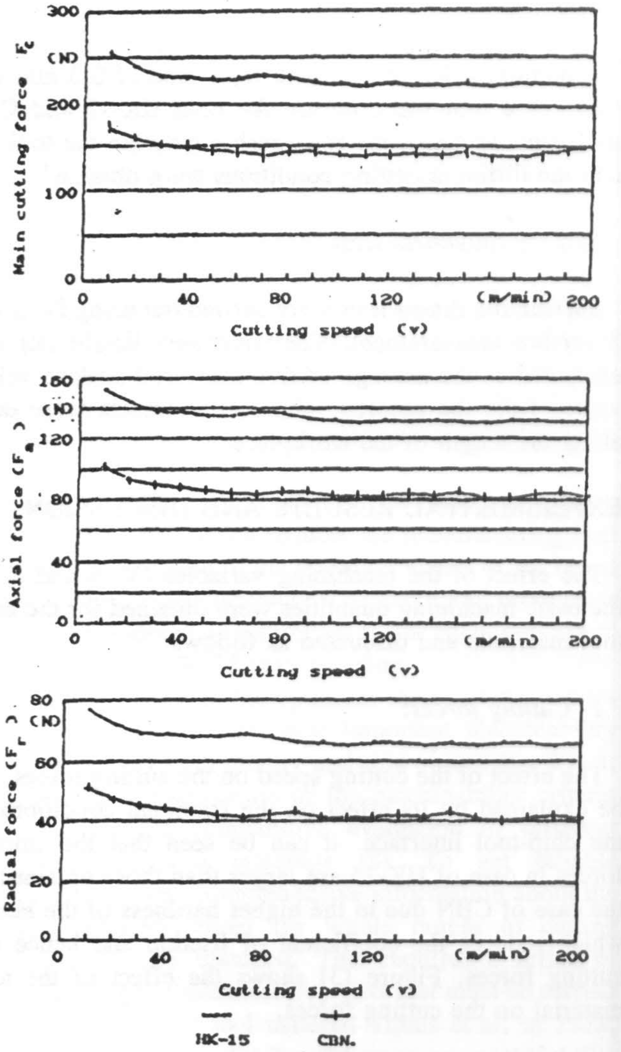

Figure 3. Effect of the tool materials on the cutting forces. (s=0.1 mm/rev., a = 0.5 mm).

2- *Cutting temperature test results*

With the increase of the cutting speed, the amount of heat generated in cutting is increased, on the other hand, the time allowed for heat transfer at the chip-tool interface is decreased, which leads to a digressive increase of the cutting temperature with the cutting speed as shown in Figure (4) for HK-15 and CBN tools. It is clear that, the cutting temperature in the case of the HK-15 is greater than that obtained for CBN due to the relatively large coefficient of friction at the chip-tool interface in case of HK-15 than CBN owing to the higher hardness of the latter.

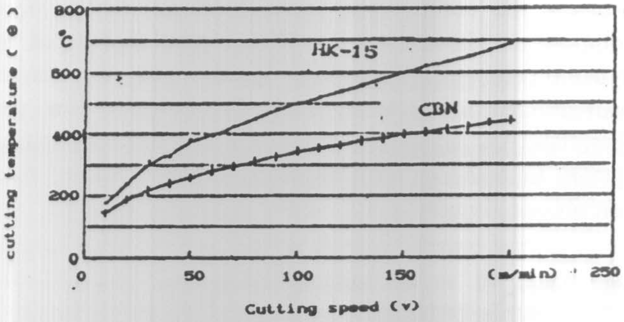

Figure 4. Relationship between the cutting temperature and the cutting speed for the used tool materials. (s=0.1 mm/rev., a = 0.5 mm).

-Cutting temperature relation-ship

The relationship between the cutting temperature and the machining variables was obtained as follows [14] :

$$\Theta = C.\ V^X.\ S^Y\ .\ a^z$$

The coefficients and the exponents (C,x,y,z) of the cutting temperature relationship were obtained for the different tool materials used as given in Table (2).

3- Tool life test results:

- Effect of the cutting speed

The (T-V) relationship obtained for the different tool materials used in the test is shown in Figure (5). As the cutting speed (V) is increased, the tool life is decreased due to the increase of the rubbing velocity and the consequent increase of the cutting temperature.

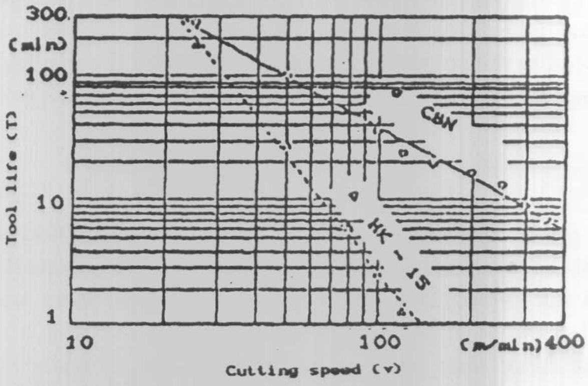

Figure 5. Relationship between the tool life (T) and the cutting speed for the used tool materials.
(s = 0.1 mm/rev., a = .5 mm).

Table 2. The obtained machinability data.

Exponents and coefficients	Tool material	
	KH-15	CBN
Forces: $F_c = K_{sc} \cdot a^{y1} \cdot s^{x1}$		
K_{sc} (kp./mm^2)	213	151
x1	0.67	0.73
y1	0.99	0.99
Cutting temperature: $\theta = C_\theta \cdot V^x \cdot S^y \cdot a^z$		
C_θ	120	100
x	0.46	0.38
y	0.233	0.2
z	0.13	0.13
Tool life: $V = \dfrac{C_v \cdot K_v}{T^m \cdot S^p \cdot a^q}$, $c_{v1} = c_v \cdot k_v$		
c_{v1}	50	570
p	0.30	0.35
q	0.18	0.16
m	0.27	0.70

- Effect of feed

The effect of the feed (S) on the tool life (T) is shown in Figure (6). It can be explained by its effect on the cutting forces and on the cutting temperature . The increase of the feed increases the cutting forces, and the cutting temperature and hence increases the wear rate and consequently decreases the tool life.

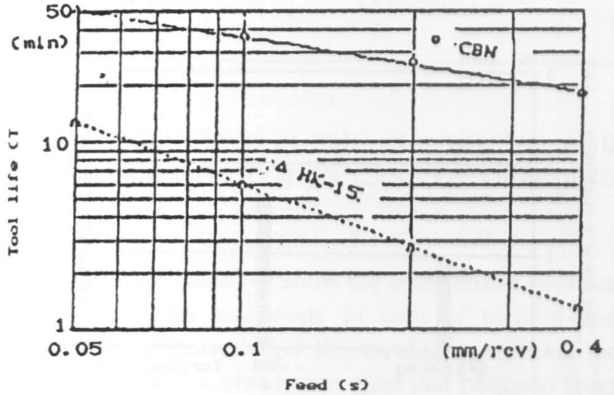

Figure 6. Relationship between the tool life (T) and the feed for the used tool materials. (v = 40 m/min, a = .5 mm).

-Effect of the depth of cut

The effect of the depth of cut (a) on the tool life (T) is shown in Figure (7). The depth of cut has much smaller effect than the cutting speed and the feed, due to the fact that its effect on the cutting temperature is considerably less than that of the cutting speed and feed. It is observed that the tool life of CBN tool material is larger than that obtained from HK-15 tools due to its lower coefficient of friction and hence the lower rubbing force and cutting temperature.

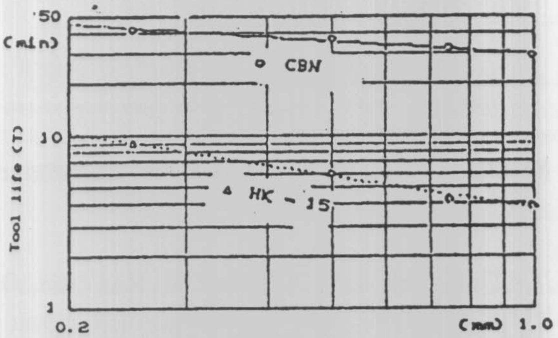

Figure 7. Relationship between the tool life (T) and the depth of cut for the used tool materials. (s = 0.1 mm/rev., v = 40 m/min).

Tool life relationship

The extended Taylor relationship between the tool life and the machining variables is given by

$$V = [\frac{C_v}{T^m . S^p . a^q}] . K_v$$

The constants and exponents of the tool life relationship for the different used tool materials are given in Table (2).

3- Surface roughness test results

The cutting speed (V) has a considerable effect on the surface roughness height (R) as shown in Figure (8) for tool materials HK-15 and CBN respectively. The roughness height (R) drops at first sharply with the increase of the cutting speed, due to the rise of the cutting temperature (Θ) and hence the reduction of the frictional force. At sufficiently high cutting speeds, the surface roughness height approaches its theoretical value resulting from the feed grooves only, . It is clear that the surface roughness for tool material HK-15 is larger than that obtained from tool material CBN. That can be explained by the higher the hardness , lower coefficient of friction and hence better chip flow conditions of CBN than HK-15.

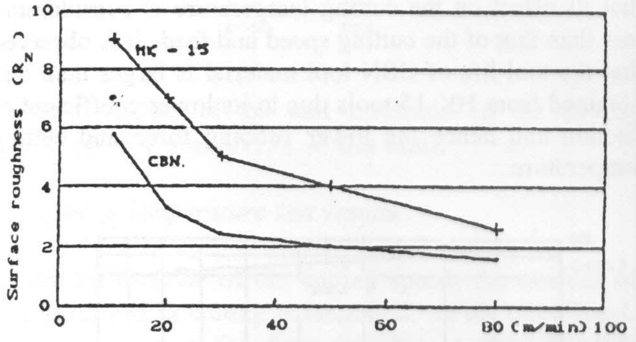

Figure 8. Effect of the tool materials on the obtained surface roughness (R_z).

CALCULATION OF THE OPTIMUM VALUES OF CUT AND MANUFACTURING COST:

The obtained machinability data shown in Table (2) were used for the determination of the optimum cutting conditions in turning [13] for machining the workpiece shown in Figure (9). The results of optimization was shown in Table 3 for HK-15 and for CBN.For the sake of comparison between machining the sprayed surfaces with turning and grinding operations,the same workpiece was machined on a cylindrical grinding machine with the following cutting conditions

- Feed = 1.5 mm/rev
workpiece rotational speed = 300 r.p.m.
grinding wheel width = 60 mm
workpiece length = 100 mm
machining allawons = 0.5 mm

The surface roughness was measured on the workpiece machined in turning with HK-15 and CBN tool materials using the calculated optimum cutting. conditions ,and in grinding, Figure (10) shows the comparison between the surface roughness(R)in the case of grinding and turning. It is observed that the surface roughness obtained from turning is sufficient for the machining of the coated spare parts. for many uses.

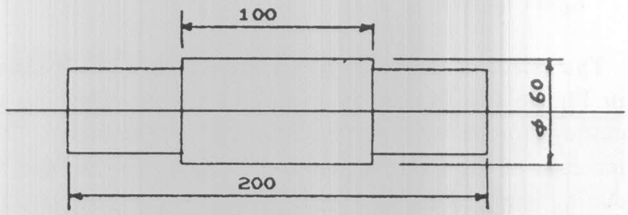

Figure 9. The workpiece used for the determination of the optimum cutting conditions.

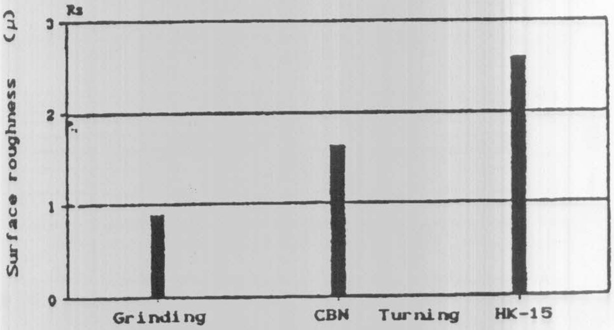

Figure 10. Comparison between the obtained surface roughness for the workpiece machined by turning and grinding.

Table 3. Optimization results.

INPUT DATA:	
Type of turning operation	External turning
Workpiece name	Cold disprayed with KH-15
Initial diameter	60 mm
Final diameter	59 mm
Claped wp. diameter	60 mm
WP. length	100 mm
Max perm surface roughness	.002 mm
Fixation method	between chuck and center.
OUTPUT DATA	
Number of passes	1
Optimum depth of cut	.5 mm
Optimum feed	.1250565 mm/rev
Optimum cutting speed	43.5204 mm/min
Optimum rotational	231.88 rpm
Optimum tool life	18.45164 min
Cutting power	.6764083 Kw
(TIME CALCULATION)	
Productive time	3.527332 min
Non productive time	1 min
Cycle time	4.527332 min
MACHINING COST	
Machine cost per piece	0.88 076 LE
Tooling cost per piece	0.66.305 LE
Layout cost per piece	0.88 LE
Material cost per piece	129.996 LE
Total cost per piece	132.8576 LE

INPUT DATA:	
Type of turning operation	External turning
Workpiece name	Cold disprayed with CBN
Initial diameter	60 mm
Final diameter	59 mm
Clamped wp. diameter	60 mm
WP. length	100 mm
Max perm surface roughness	.002 mm
Fixation method	between chuck and center.
OUTPUT DATA	
Number of passes	1
Optimum depth of cut	.5 mm
Optimum feed	.1 mm/rev
Optimum cutting speed	62.13354 m/min
Optimum rotational	329 rpm
Optimum tool life	87.87726 min
Cutting power	.4568602 Kw
(TIME CALCULATION)	
Productive time	3.03374 min
Non productive time	1 min
Cycle time	4.03374 min
MACHINING COST	
Machine cost per piece	0.75 LE
Tooling cost per piece	3.42 LE
Layout cost per piece	0.75 LE
Material cost per piece	129.996 LE
Total cost per piece	134.82 LE

COMPARISON BETWEEN THE MACHINING AND MANUFACTURING COST IN CASE OF GRINDING AND TURNING

Figure (11) and Table (4) show the comparison between the machining time and costs in case of turning and grinding. It is observed that the turning operations the machining time and costs are less than that obtained from grinding .On other hand it is observed that the machining cost in case of HK-15 is less than that obtained from machining the workpiece with CBN tool.

Table 4. Comparison between the machining and manufacturing costs in case of turning and grinding.

machining method	griding	turning	
		KH-15	CBN
machining cost (LE)	44.4	2.46	4.98
manufacturiong cost	174.4	132.81	134.87

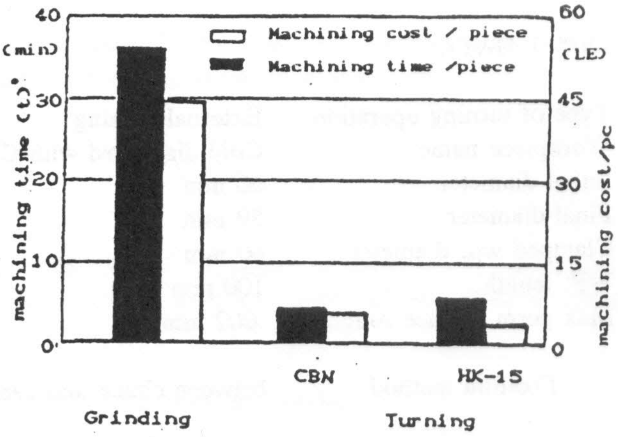

Figure 11. Comparison between the machining time and costs in case of turning and grinding. for - ϕ 60 mm, L = 100 mm - machining allowance = 0.5 mm.

CONCLUSION

According to the experimental work and the obtained experimental results, it can be concluded that:

1- The cutting forces and the cutting temperature in case of CBN cutting tool are lower than those obtained in case of HK-15 by about 40 %. and 37% respeciively under the same cutting conditions due to the relatively higher hardness of CBN. which leads to the lower coefficient of friction. On other hand the optimum tool life for CBN is about 4 times that obtained for HK-15 while the optimum cutting speed of CBN is also 1.47.

2- Comparing the tooling cost/piece for CBN and HK-15 using the optimum cutting conditions for each tool material it is found that; the tooling cost for CBN is 8 times that for HK-15. The corresponding machining cost/piece in case of CBN is about 2.4 that HK-15 due to relatively higher capital cost of CBN tip.

3- Turning using CBN leads to the decrease of machining time by 93% and cost by amount of 88% than by grinding, while the use of HK-15 leads to the decrease of machining time by 90 % and cost by amount of 95 % than grinding.

4- The surface roughness R in case of turning using CBN is found to be 1.6 μm, while that obtained using HK-15 is found to be 2.6 μm., using the optimum values of cut determined for each tool material. On the other hand, the surface roughness obtained in case of grinding is found to be 1.0 μm.

5- From the economic point of view, grinding can be practically replaced by turning using either CBN or HK-15 without a considerable sacrifices with the product quality. In general, it can be expected that grinding of relatively harder material can be successfully replaced by turning using such hard tool material as CBN or HK-15.

6- It can be recommended that HK-15 tools are more economic then CBN tools for machining the cold sprayed materials under investigation. The use of CBN is not justified in this case due to the relatively lower hardness of sprayed material and the relatively higher capital cost of CBN. It is expected that for sufficient harder material the use of CBN may be justified.

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