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Investigation on the Application of Worn Cutting Tool Inserts as Burnishing Tools

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The amount of wear in cutting tools used in all machining processes is around 1 % to 2 % evaluation of the non-wearing areas of the inserts is economically beneficial. This study aims to test the usability of the non-wearing regions of the waste tungsten carbide (WC), cubic boron nitride (CBN) and ceramic inserts as a rolling tool in the deep rolling method and to observe their performance. The turned workpieces were deep rolled with three different types of waste-cutting tools (WC, CBN and ceramic) in different machining parameters (rolling force, number of passes, and feed rate). As a result, surface roughness and microhardness values obtained in deep rolling operations with these inserts were similar to those in deep rolling operations with other rolling tools. It has been determined that ceramic inserts perform better in deep rolling processes in terms of microhardness, and WC inserts perform better in terms of surface roughness. Thus, it has been determined that waste WC, CBN and ceramic inserts can be used in the deep rolling method.
Keywords: deep rolling, ball burnishing, microhardness, tribology, surface roughness

Highlights
- *Deep rolling process is a surface treatment process that has been studied in recent years.*
- *The inserts (WC, ceramic, CBN, etc.) used in machining processes have areas that are largely (≈ 98 % to 99 %) non-worn after use.*
- *The use of non-worn areas of these tools is very valuable from economic and environmental points of view.*
- *The use of these waste inserts in deep rolling processes is an alternative.*

0 INTRODUCTION

The cutting insert wear occurs at a rate of 1 % to 2 % in machining applications, and after this damage, they are junked [1], which is a great loss in terms of economy and environment. Recycled WC makes up nearly 20 % and 30 % of the total production according to statistics. Retrieving tungsten carbide decreases the raw material cost between 15 % and 50 % [2]. All these reasons make the studies related to re-evaluation of these cutting tools that have become wasted very significant. The increasing metal demand throughout the world has encouraged intensive studies for extracting metals from low grade ores and/or from secondary sources [3]. Among these metals, the main raw materials of cutting tools such as tungsten carbide (WC), cubic boron nitride (CBN) and ceramic, are the most important materials in industrial applications [3]. Since the production of cutting inserts is a very costly process, regaining these inserts through recycling makes the process more important [4]. Besides the benefit that recycling studies bring together with them [5], it is an expensive process, which encourages seeking different alternatives. This makes the reuse of waste-cutting inserts important.

The deep rolling process is a surface treatment process. Deep rolling that Ford Company first applied to axle shafts dates back to the 1930s [6]. The basic mechanism in this method is the surface pressure effect created between a workpiece and a spherical ball end in the contacted area, as explained through Hertzian theory [7]. As a result of this surface pressure, residual tensions and micro structural deformations (hardening/ softening) occur since the yield force of the material is exceeded [8], [9], and [6]. Studies about deep rolling are still continuing in various ways, such as simulation works about deep rolling [10], deep rolling analysis through finite elements method [11], and [12], trials of deep rolling in different work conditions (for example: cryogenic) [13], and deep rolling analysis through regression methods etc.. It is seen that hardness, corrosion resistance and fatigue life have been obtained as a result of press residual stress formed on the surfaces by deep rolling [14]. The good surface quality obtained and the spreading possibility of fatigue cracks are counteracted by residual press stresses [14]. Deep rolling nitration, similar to that of induction hardening and hardening with laser processes, has effects on the surface of the workpiece at values close to the values of surface penetration depth [6].

The cutting tools used in machining processes have areas that are largely (≈ 98 % to 99 %) non-worn after use. Except for the studies on recycling cutting tools, no studies were found in the literature on the evaluation of unused surfaces of inserts. In order to

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achieve this aim, the non-worn insert areas on the surfaces of cutting tools were used as the crushing edge in the deep rolling method, and thus, it was recovered again. In this context, three different cutting insert types (WC, CBN and and ceramic) that had become waste were selected and processed by a deep-rolling method with different processing parameters of AISI 1050 steel. Thus, the applicability of the deep rolling method in the recycling of these inserts was investigated. The performances of the inserts used were compared in terms of microhardness, surface roughness *(Ra)* and the resulting surface appearance. The aim of this article is not to analyse deep rolling, but to detail whether the waste inserts achieve the results in deep rolling or not.

1 MATERIALS AND METHODS

A SMARC brand CAK6166B X 200 model computer numerical control (CNC) lathe was used in all turning operations (Fig. 1a). In the cutting process in general turning operations, the upper surface of the cutting tool is aligned with the workpiece axis. In this study, in the deep rolling process, the middle region of the used and worn cutting edge was aligned in the same direction of the workpiece axis (Fig. 1b). Henceforth, the used waste insert will be called the roll insert. The roll insert was mounted on the CNC lathe turret with a specially designed tool holder (Fig. 1c).

In order to adjust the pressure force of the cutting tool and the tool holder, the pressure force was adjusted by changing the spring length as a result of the connection apparatus that was specially designed and connected to the turret. Three different clamping force values adjusted according to the spring pressure lengths in the spring catalogue **[15]** were selected (Fig. 1c). The pressure forces were not separately measured during the experiment, yet the table values were taken as reference.

Here, the basic aim is to investigate and measure the effects according to force increase rather than measuring the forces. In all deep rolling processes, three different roll inserts were used. The inserts were chosen from different types of each group, such as the PVD-coated M30 series (WC) (82 % WC + 5 % titanium carbide (TiC) + 10 % Co), (CBN) and ceramic. All cutting inserts chosen were previously used and became waste materials (Fig. 2).

AISI 1050 steel (20 mm diameter and 70 mm long) was used in the experiments. The work piece with an 18 mm diameter was primarily finish applied material. The average hardness of the material before rolling was measured as 220 HV0.5 to -240 HV0.5.

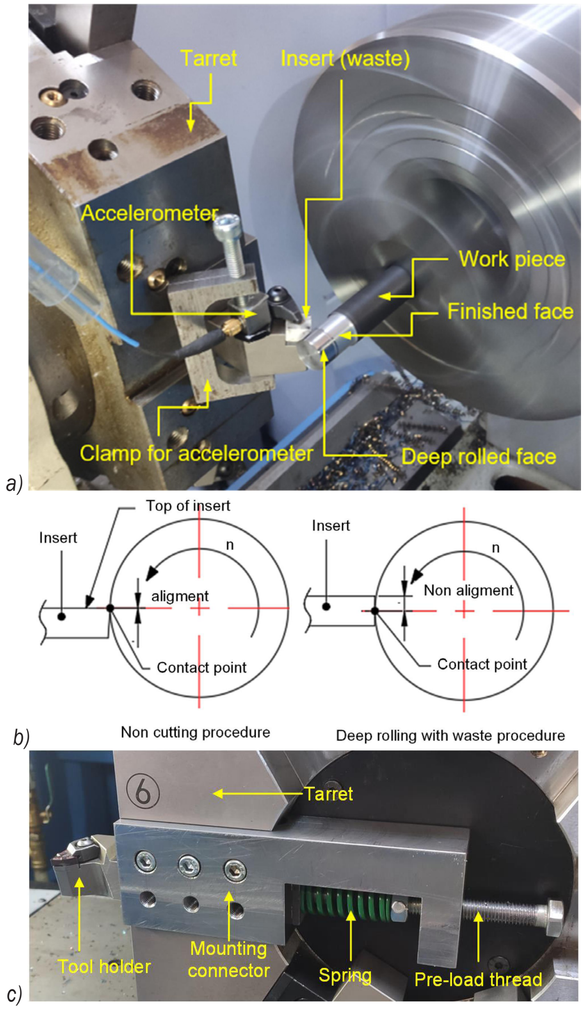

Fig. 1. *Schematic representation of conducting deep rolling and aligning waste cutting tool with workpiece a) All operations b) tool alignment c) tool holder*

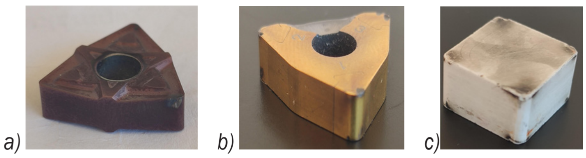

Fig. 2. *Different waste inserts a) WC, b) CBN, and c) ceramic*

In the experiments, three pressure forces (143 N, 330 N and 495 N), three passes (1, 2 and 3) and three feed rate values (0.04 mm/rev, 0.08 mm/rev and 0.12 mm/rev) were selected. Thus, for each inserts, 27 experiments (Table 1), 81 experiments in total were performed for all inserts.

No cooling was used in the experiments. Variance analysis was performed to examine the effect of process parameters on the results for both microhardness and *Ra*.

Table 1. *The design matrix for the experiments*

Exp. No	Insert	Number of passes	Feed rate [mm/rev]	Force [N]
1	WC –CBN-Ceramic	1	0.04	143
2		1	0.08	143
3		1	0.12	143
4		2	0.04	143
5		2	0.08	143
6		2	0.12	143
7		3	0.04	143
8		3	0.08	143
9		3	0.12	143
10		1	0.04	330
11		1	0.08	330
12		1	0.12	330
13		2	0.04	330
14		2	0.08	330
15		2	0.12	330
16		3	0.04	330
17		3	0.08	330
18		3	0.12	330
19		1	0.04	495
20		1	0.08	495
21		1	0.12	495
22		2	0.04	495
23		2	0.08	495
24		2	0.12	495
25		3	0.04	495
26		3	0.08	495
27		3	0.12	495

27 for each insert, 81 total experiments

For each pass, an equal 0.04 mm depth of pass was applied. For the microhardness, 27 pieces from the parts with a feed rate of 0.08 mm/rev were selected. Microhardness was measured from at three different points of the cylindrical surface of each selected part and was assigned by calculating the arithmetic average of the three values measured. For the face microhardness, the microhardness was measured as 10 values by shifting 70 µm from the edge to the axis of the part. For the surface roughness, the arithmetic mean of *Ra* values measured from three different areas of each cylindrical surface was accepted as the surface *Ra* of the experiment sample.

2 RESULTS AND DISCUSSION

2.1 Tool Wear

The purpose of the study to re-evaluate waste-cutting tools by using them in the rolling process. The damages occurring in the nose part of the cutting tools are shown in Fig. 3.

Fig. 3. *The worn areas in inserts*

Three different types of roll inserts shown in Fig. 6 were calculated as both insert wear length *(Vbmax)* and the worn area (*A*), and the results are shown in Table 2.

Table 2. *Worn area values*

Tool type	*Vbmax* [mm]	Area, *A* [mm^2]
WC insert	1.1525	1.059
CBN	1.236	0.910
Ceramic	1.339	0.758

In the observations, no significant wear was observed on the surface of all three insert types. In the WNMG and CBN insert types, it was observed that the coating layer was erased, but no trace of abrasion was formed on the surface (Fig. 6a and b). Only a black zone has formed due to heat and abrasion. Of the insert types used, the ceramic tip is uncoated. As seen in Fig. 6c group, there was no significant wear-related damage on this insert type; only a black area was caused by heat and dirt. What is expressed as *Vbmax* here is not actually the wear value in the real sense but is expressed only as the dimensional length of the trace formed. From the results obtained, it is possible to say that every insert type can be used in deep rolling. Considering Table 2 data, it is seen that the dimensional lengths of the traces (here as the edge wear length *(Vbmax)*) are close to each other. When the sizes of the areas formed by the traces are examined, it is seen that the largest area is with the WC-type insert, and the smallest area is with the ceramic-type insert.

2.2 Microhardness

Microhardness measurements were carried out to examine the number of passes in the radial direction on the face surface of the simples, and the microhardness values graph of values from cylindrical surfaces are seen in Fig. 4a. When the graph of Fig. 4a is examined, it is seen that there is an increase in the hardness caused by deep rolling on the surface of the workpiece. This situation presents parallelism with the results of many studies in the literature [16] to [18].

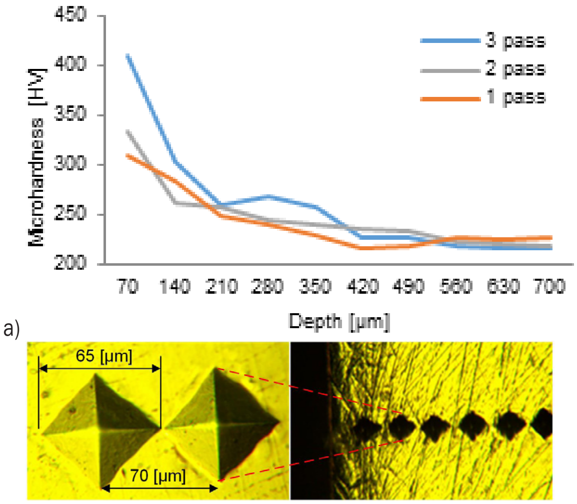

Fig. 4. *a) Microhardness graph in radial direction, b) status of traces, and c) surface distribution of traces*

It was also stated that the highest hardness occurred on the surface and the hardness decreased from the surface to the centre [12], [14], [18] and [19]. Abrão et al. [20] stated that for AISI 1060 steel, with the increase of rolling pressure and the number of passes, the intensity of the plastic stress under the surface increased, resulting in an increase in both the microhardness value and the depth of the affected zone. Loh et al. [21] found that the surface hardness of medium carbon steel increased by an average of 55 % after deep rolling with tungsten carbide balls. Also, rolling pressure and feed rate were found to be the most important factors in microhardness [22]. As can be seen in Fig. 4a, the highest hardness value was obtained in the experiment with three passes, and the lowest value was obtained in one pass.

There is a difference in surface hardness up to 500 μm below the surface. Studies on deep rolling show that the depth of the affected area varies between 500 μm to –1 μm [13], [16] and [20]. This depth varies according to material type, process parameters and application environment (cryogenic, etc.).

When each insert type was analysed according to the values, the graphic in Fig. 5 were obtained.

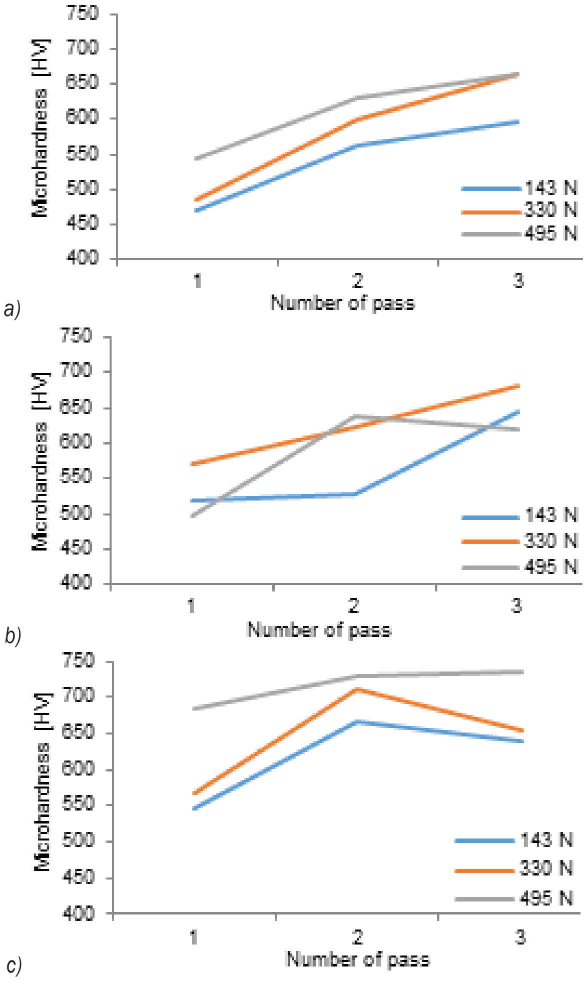

Fig. 5. *Microhardness graphs according to insert types; a) WC, b) ceramic, and c) CBN*

This effect is also seen in other studies [12]. Parallel to this, the increase in the number of passes at all inserts also causes an increase in hardness.

It is seen that the highest hardness values are obtained with the ceramic insert, and the lowest hardness values are obtained with the WC insert.

When the values in Fig. 5c are evaluated, it can be said that the use of ceramic inserts in deep rolling is more convenient in terms of microhardness. In applications for which hardness is required, ceramic inserts and high pass numbers are recommended. In general, it is seen from the graphs that instabilities in the CBN inserts occur with the increase in the pressing force. It is estimated that these instabilities are due to the instabilities on the surface of the work piece. In general terms, it is possible to say that the hardness increases in both the surface and radial directions in the deep rolling method for all inserts. This did not change in the use of waste inserts. It should also be noted that compared to previous studies, hardness values can be quite misleading in evaluating the hardening state because increases in hardness values are also induced by compressive residual stresses **[23]**.

When Fig. 5 is examined, it is seen that the hardness of all inserts increases with the increase of the pressure force. Depending on the material, deep rolling can result in the formation of dislocation cell structures **[24]**, nanocrystals **[9]** and **[25]**, twinning **[18]** or martensitic transformations **[18]**.

When the surfaces with microhardness values are examined, it is seen that quite different structures are formed within the same region (Fig. 6). In deep rolling, temperature is one of the most important criteria. The main source of formations on the surface is temperature **[13]** and **[19]**. As a result of plastic deformation of the surface (with changes in parameters such as feed rate, number of passes etc.), increases in temperature occur. Also, with effects such as a high feed rate, more force (partially converted to heat in the ball-work piece contact zone) is required for rolling **[12]**. In addition, the increased heat from the wear mechanism causes the structure to transform from ferrite to perlite or martensite. Accordingly, it is observed that carbide bands are formed (Fig. 6).

Maximov expresses the work obtained in the thermodynamic explanation of the tool and workpiece in the deep rolling process in Eq. (1) **[19]**.

$$\overline{dA}^{e} = dA_{Q}^{e} + |dA_{el}| + |dA_{pl}|. \tag{1}$$

Here $\overline{dA}^{e}$ the external (input) work, dA_{Q}^{e} the work converted into heat and $|dA_{el}| + |dA_{pl}|$ are the elementary works of the external and the internal surface forces for the elastic and plastic deformation of the workpiece, respectively. Accordingly, the rise in temperature is an important parameter of the work achieved in deep rolling. Temperature increases on the workpiece thermodynamically have an improving effect on the work obtained. In the graphs in Fig. 8, it is seen that the hardest structure is the ceramic tip, followed by the CBN and WC tips, respectively. Since the thermal conductivity of WC-type and CBN-type inserts (60 W/(m K) to –80 W/(m K)) is higher than the thermal conductivity of ceramic inserts (10 W/(m K) to –20 W/(m K)) **[26]**, WC and CBN inserts take most of the heat generated on themselves and do not transfer it to the material surface. Unlike WC and CBN inserts, since ceramic inserts have

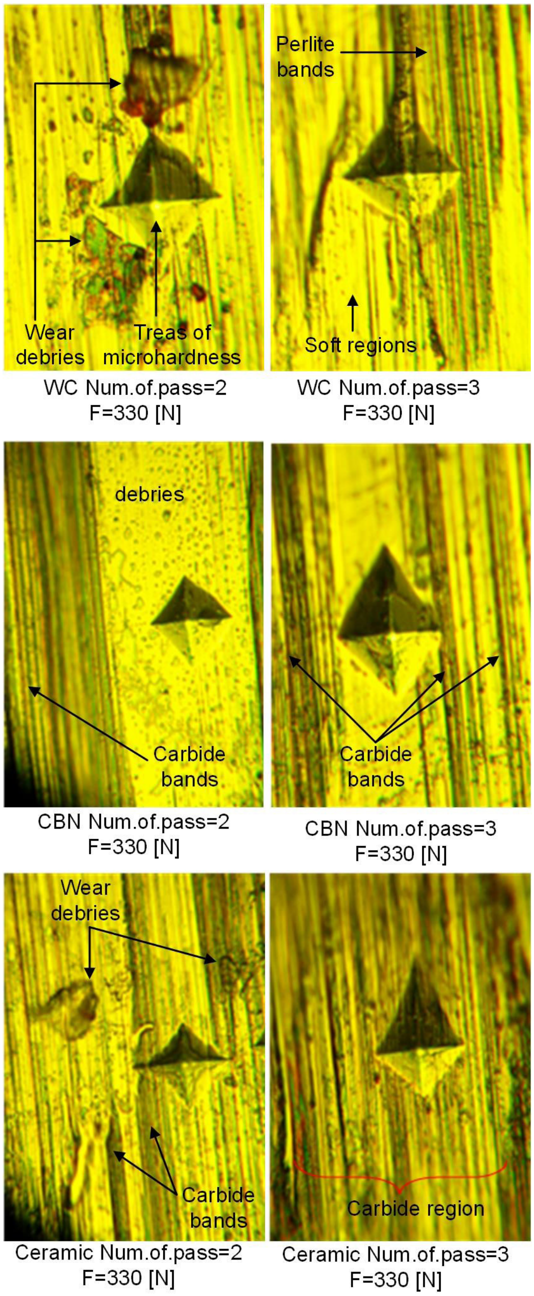

Fig. 6. *Images of structures on surfaces*

lower thermal conductivity, most of the heat generated in deep rolling is transferred to the workpiece. It is thought that [19] phase transformations occur thermodynamically as a result of the heat staying more on the workpiece, and as a result, the hardness increases. It is thought that the reason for the high hardness values in deep rolling with ceramic-type inserts is in this direction. Similar to this idea, in their study of carbon steels, Abrão et al. and other researches [17], [20] and [27] stated that partial annealing, full annealing or quenching and tempering occur on AISI 1060 steel material. In particular, it was stated that the pressure force and the number of passes significantly increase the hardness [20]. In contrast, since the ferrite layers are transformed into perlite in the heat transfer, it was observed that the microhardness increases accordingly [19].

The results in Table 3 were obtained as a result of the ANOVA analysis performed to investigate to what extent the process parameters affected the microhardness. When the variance analysis table is examined, the values under the column shown with the *P*-value indicate whether the independent variables are statistically significant on the dependent variables. The fact that the *P*-value is less than 0.05 indicates that this value is statistically significant. In this regard, it can be seen that the insert type, force, and number of pass parameters on microhardness are statistically significant. It is the "Contribution" value that shows the effect of independent variables on dependent variables. Accordingly, it can be seen that the number of passes, insert type, and force are effective on microhardness by 44.77 %, 23.70 % and 13.53 %, respectively. This shows that deep rolling of

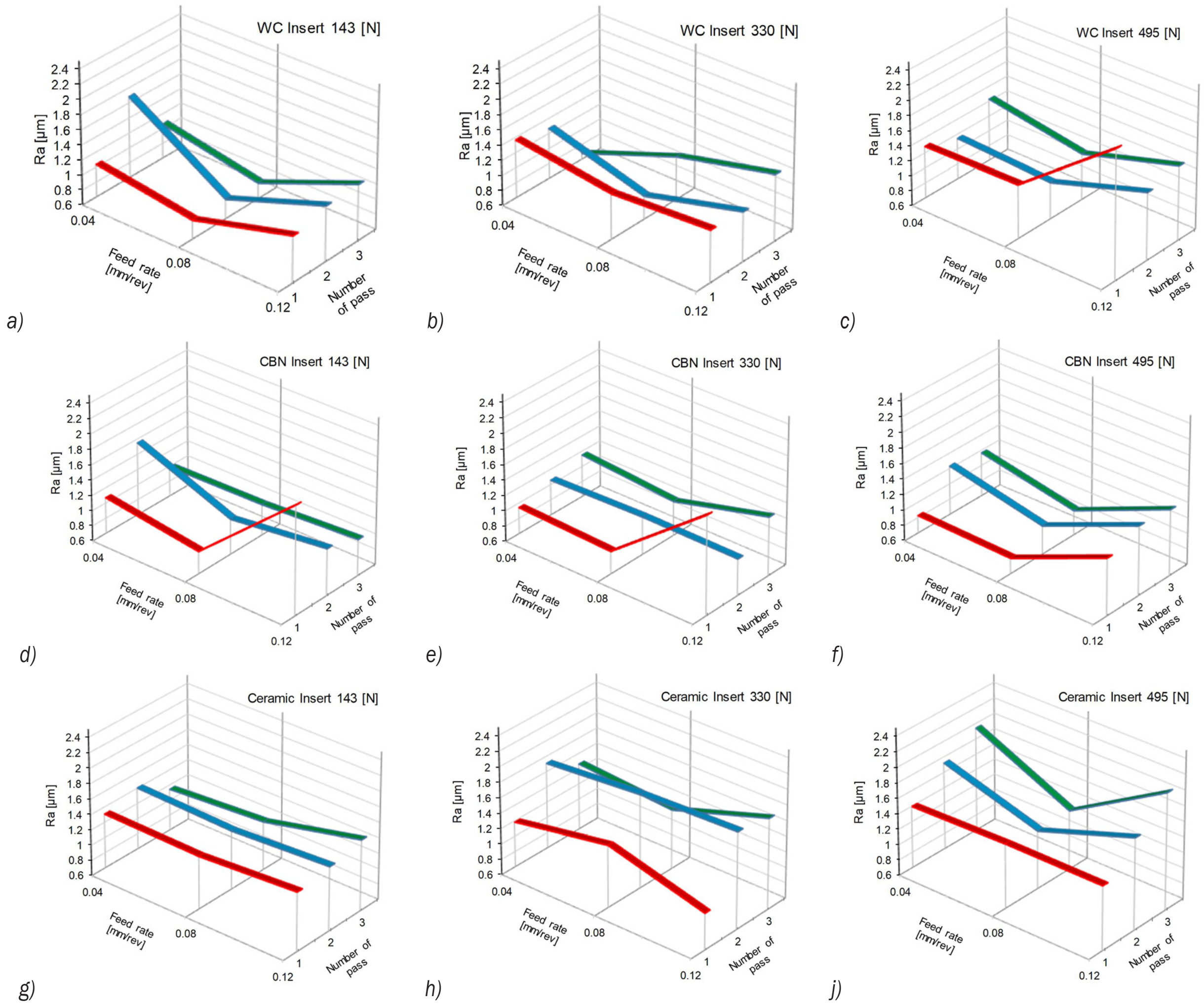

Fig. 7. *Ra values measured according to feed rate and number of passes*

Table 3. *ANOVA for microhardness*

Source	DF	Seq SS	Contribution [%]	Adj SS	Adj MS	F-value	P-value
Insert type	2	33670	23.70	33670	16835	13.16	0.000
Force [N]	2	19218	13.53	19218	9609	7.51	0.004
Number of passes	2	63616	44.77	63616	31808	24.87	0.000
Error	20	25578	18.00	25578	1279		
Total	26	142081	100.00				

waste insert inserts produces a result parallel to the literature [17], [19] and [28].

When the graphs in Fig. 5 and the images in Fig. 6 are evaluated together with variance analysis, it is seen that the insert type is also effective as the number of passes increases. Each pass causes more deformation on the surface, resulting in a tougher structure and more carbide formation on the material surface, which is observed as an increase in microhardness. With each pass, the peaks on the surface fill into the valleys on the surface. If more passes are applied after a certain stage, a mechanism similar to sliding-rubbing occurs between the material and the crushing tip. This situation causes the formation of debris and carbide bands similar to the one in Fig. 6. The number of passes having the greatest impact here is perhaps due to the filling of the valleys on the surface after the 1st or 2nd pass and the burnishing turning into sliding-rubbing after this stage. Therefore, more work is needed to obtain optimum values. When an excessive number of passes or rolling force is applied, the surface turns into a mechanism similar to ploughing, as in the grinding process.

The fact that some of the slopes in Fig. 5 do not occur linearly or logarithmically can be defined as a result of the unstable structures formed.

2.3 Surface Roughness

Each insert was separately examined according to *Ra* values and relevant rolling force obtained, and the results are shown in Fig. 7. When Fig. 7 is examined, it is seen that the lowest *Ra* values are obtained when $f = 0.08$ mm/rev according to the different feed values selected. Low and high feed rates have a negative effect on *Ra*. This shows that optimum feed rates must be achieved in deep rolling.

Data showing a direct relationship between progress and *Ra* could not be obtained from the graphs in Fig. 7. Prabhu et al. found the coefficient effect of progress on *Ra* very low in their regression and ANOVA analysis in deep rolling of AISI 4140 steel [29].

In deep rolling, the surface of the workpiece is exposed to more heat as the time to reach the maximum temperature increases with the decrease of the feed value. In Figs. 7g, h and j graphs, higher *Ra* values were obtained in ceramic inserts. Here too, we believe that the temperature factor is effective. It is thought that the surface structure deteriorates due to the heat accumulated on the surface formed at the ceramic inserts, and as a result, increases in *Ra* values occur.

Similarly, in another study, it is stated that the decrease in feed causes the deformation of the surface layers near the roll insert, resulting in higher workpiece temperatures. It is stated that at higher feed rates, more power (partially converted to heat in the ball-work piece contact area) is required for deep rolling [12].

The low and high progress therefore, causes negative effects on the surface in terms of *Ra*. From all this, we are of the opinion that optimum values should be applied for progress rather than low or high. In all graphs in Fig. 7, the *Ra* value was mostly obtained at 0.08 mm/rev as the optimum value. Considering the situations where the rolling force is low, it is seen that lower *Ra* values are obtained in WC inserts than in CBN inserts (Figs. 7a, and d). However, when the rolling force is increased (Figs. 7b, c, d, and e), it is seen that CBN inserts have a more positive effect on *Ra*.

Here, it can be concluded that the best *Ra* values are obtained in WC inserts with low rolling forces and in CBN inserts with high rolling forces. In addition, according to these results, it can be said that the use of ceramic inserts in deep rolling applications where *Ra* values are intended to be low is not appropriate compared to other insert types. It is observed that *Ra* values generally increase with the increase in the number of passes in the WC insert (Figs. 7a, b, and c). However, the same trend cannot be said for CBN (Figs. 7d, e, and f) and ceramic (Figs. 7g, h, and j) inserts. In this respect, it can be said that the insert type, which is parallel to the literature in terms of *Ra* values to be obtained, is WC-type inserts. Studies show that *Ra* values decrease with the increase in the number of passes [28] and [29] and the most effective parameter on *Ra* is the number of passes [29].

The graphs obtained in order that the effect of the rolling force in connection with feed rate on *Ra* can be better understood are presented in Fig. 8. Although it is said that the increase in the rolling force causes an increase in *Ra* [20] and [29], there are also studies indicating that the increase in the rolling force leads to worse surface quality [28]. While interpreting this situation, some studies stated that when the rolling force exceeds a certain value, deterioration occurs as a result of overloading the material. Abrão et al. found that for AISI 1060 steel, high-pressure values produced higher *Ra* values than more moderate-pressure values [28].

In deep rolling, the surface of the workpiece is exposed to more heat [12] and [29] as the time to reach the maximum temperature increases with the decrease of the feed rate value. This causes unstable *Ra* values to occur in WC-type inserts at a low feed rate, depending on the rolling force and the number of passes (Fig. 8a). At higher feed rates, a more balanced distribution and an increase in *Ra* values are observed with the increase in rolling force (Figs. 8b, and c).

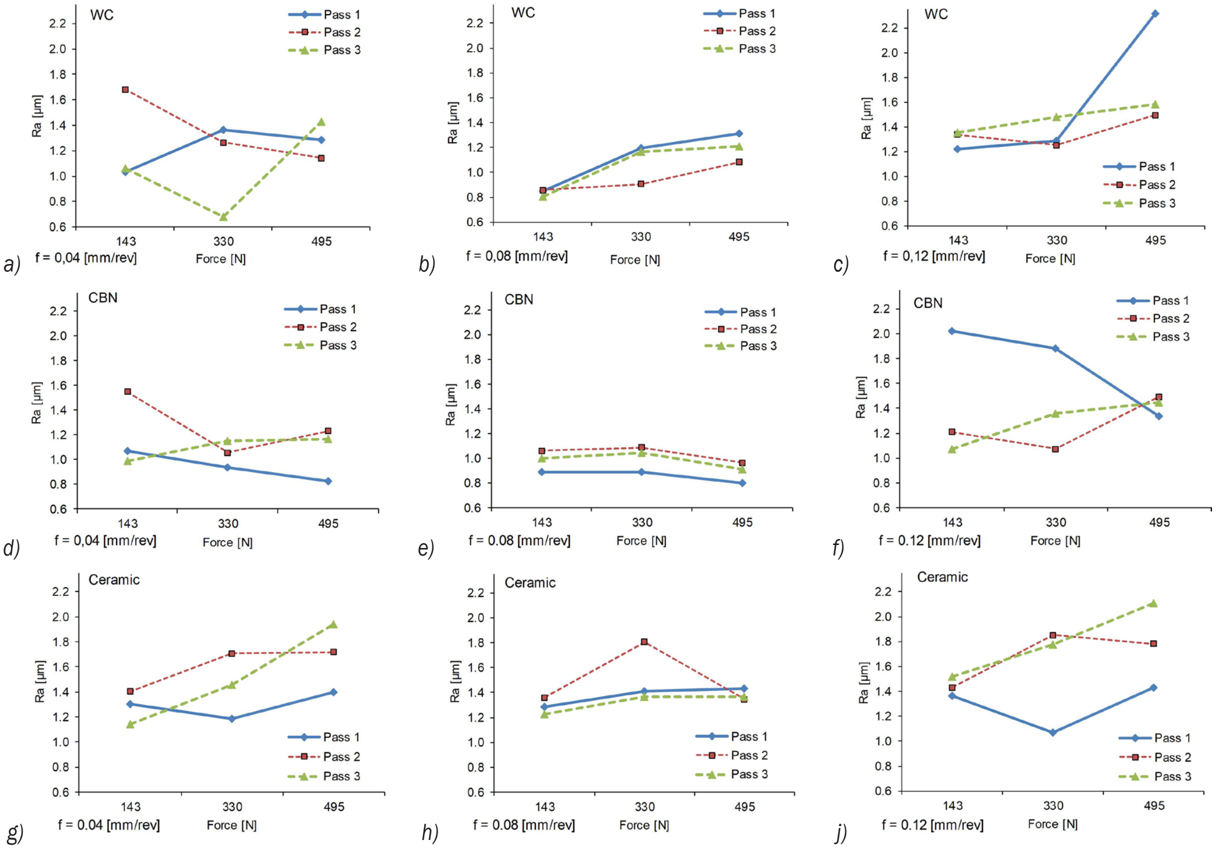

Fig. 8. *Display of the relation between rolling force and feed rate values according to inserts a,b and c) WC, d, e and f) CBN, and g, h and j) ceramic inserts*

Table 4. *ANOVA for surface roughness (Ra)*

Source	DF	Seq SS	Contribution [%]	Adj SS	Adj MS	F-value	P-value
Insert type	2	1.50865	18.23	1.50865	0.75433	12.18	0.000
Force [N]	2	0.37534	4.54	0.37534	0.18767	3.03	0.054
Number of passes	2	0.06379	0.77	0.06379	0.03189	0.52	0.600
Feed rate [mm/rev]	2	1.87061	22.60	1.87061	0.93531	15.11	0.000
Error	72	4.45776	53.86	4.45776	0.06191		
Total	80	8.27616	100.00				

When Figs. 8a, b and c are examined, it is seen that the lowest *Ra* values are *f* = 0.08 mm/rev for WC-type inserts, and *Ra* values close to each other are obtained when the number of passes is two and three. Abrão et al. [28] stated that there is a decrease in *Ra* value after 50 bar pressure value, and deterioration occurs after 100 bar for AISI 1060 steel. They stated that the reason for this is the deterioration and spalling in the plastic flow. In Figs. 8b and c, it is understood that the compression value of 143 N for AISI 1050 steel is the most appropriate rolling force value for low *Ra* values in WC-type inserts.

Looking at the CBN insert type, it is seen that the most stable and ideal feed is *f* = 0.08 mm/rev, similar to the WC insert type (Fig. 8e). However, here, unlike the WC insert type, *Ra* values decrease with increasing rolling force (Fig. 8e). In this insert type, it is understood that the most unstable and highest *Ra* values are *f* = 0.12 mm/rev (Fig. 8f). *Ra* values at low (*f* = 0.04 mm/rev) and medium feeds (*f* = 0.08 mm/rev) are quite low for this insert type (Figs. 8d, and e). In this type of insert, the ideal conditions for *Ra* are low pass number, medium feed value (*f* = 0.08 mm/rev) and high rolling force values.

When looking at the ceramic insert type, it is seen that higher *Ra* values occur in all cases compared to WC and CBN insert types (Figs. 8g, h and j). In this insert type, an increase in *Ra* values is observed with an increase in rolling force. As explained, it was concluded that the formed high temperature remains on the workpiece due to the low thermal conductivity coefficient of the ceramic insert, and as a result, both instability and surface deterioration occur. It is seen that the ideal feed rate is *f* = 0.08 mm/rev in the ceramic insert type as in the other insert types (Fig. 8h). When this type of insert is used, low rolling force, low pass number and medium feed values should be chosen.

Variance analysis was performed to see the interaction of *Ra* and process parameters, to determine the effect rate of the parameters on *Ra*, and to examine the issue statistically. As a result of the variance analysis, the values in Table 4 were obtained.

When the variance analysis table (Table 4) for *Ra* is examined, it is seen that the insert type and feed rate values on surface roughness are statistically significant. When the "Contribution" values, which reveal the effect of independent variables on the dependent variable *Ra*, are examined, it is seen that the most effective parameter on *Ra* is the feed rate. The effect ranking on the dependent variable *Ra* was obtained as 22.60 %, 18.23 %, 4.54 % and 0.77 % for feed rate, insert type, force and number of passes, respectively. The fact that the effect percentage rates here are not significantly different from each other prevents reaching a very clear conclusion for federate and insert types, which have a significant effect on *Ra*. Even in the research referenced in the evaluations made for Fig. 8 above, no definite conclusions in machining could be reached. In this respect, more studies are needed to form certain opinions and formulations on deep rolling.

3 CONCLUSIONS and SUGGESTIONS

The following conclusions and suggestions have been listed for WC, CBN and ceramic inserts used in the deep rolling process in order to have wasted cutting tools regained:

- In the deep rolling process with waste inserts, good results are obtained with WC and CBN type inserts in terms of surface roughness, and ceramic inserts in terms of microhardness.
- When the rolling force and pass numbers increased, it was seen that the microhardness in all types of inserts increased. The increase in microhardness is due to the increase in subsurface plastic stress intensity as a result of the increase in pressing force and number of passes.
- It was observed that the highest hardness values were obtained from ceramic inserts, while the lowest values were obtained from WC inserts. This situation is explained by the higher temperature increase on the surface due to the low thermal conductivity of ceramic tips.
- Medium feed rates are suitable for all insert types for AISI 1050 steel, and in this study, this value was established as *f* = 0.08 mm/rev. In WC cutting inserts, unstable *Ra* values formed with regard to rolling force and number of passes in low feed rates. It is thought that the high thermal conductivity of this insert type and the temperature increase on the surface at low feed are the sources of the unstable structure formed.
- In ceramic type insert, it was seen that in general, *Ra* values increased with the increase in rolling force. Thus, when this type of insert is used, low rolling force, pass numbers, and medium feed should be chosen.
- In CBN-type inserts, it was seen that *Ra* values decreased with the increase in rolling force. For this type of insert, the ideal conditions for *Ra* values occur at low pass numbers, medium feed value (*f* = 0.08 mm/rev) and high rolling force.
- It was determined that the 143 N rolling value for AISI 1050 steel was the most suitable rolling force

for low *Ra* values in WC-type cutting inserts. WC inserts give good results in low rolling forces. This is due to reduced surface deterioration combined with lower heat generation.

In all conditions, optimum values of process parameters must be obtained in terms of surface deformation, temperature, and stress.

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