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CHARACTERIZATION OF RESIDUAL STRESSES INDUCED INTO BEARING RINGS BY MEANS OF SOFT TURNING USING DIFFERENT TURNING PARAMETERS

Residual stresses are those stresses which remain in solid materials after removing the external load. Residual stresses which are induced by machining processes play important role in determining the service life of the machined components, depending on its magnitude, sign, and direction. This research provides a comprehensive correlation between three turning parameters and the resulting residual stresses formed on the surface of the outer ring of tapered roller needle bearing, made of 100CrMnSi6-4 type steel. The examined parameters were cutting speed, feed and tool nose radius. Radial and axial residual stresses on the surface were measured using sample cutting-free X-ray diffraction method. It is shown that the effect of one processing parameter can even be opposing depending on the other parameters. Thus, the effects of turning parameters on residual stresses must be examined in a comprehensive manner.

1. INTRODUCTION

Surface integrity of machined components has great importance in determining its service life [1 ‹2]. It has many elements like roughness, hardness, microstructure and residual stresses [3, 4]. After machining, for instance, turning, these factors affect the fatigue life and stability of the component’s surface [5]. Thus, studying the effect of these factors on the machined parts, and aiming to find the optimal machining parameters is of great significance. The final stresses within the turned workpiece depend mainly on the turning parameters that have been used [5]. Consequently, it is important to know the ideal combination of these parameters that will lead to favorable residual stresses to improve the surface integrity of the part [6].

Researchers have put more than one explanation about the origin of residual stresses creation after turning. According to one of them [7], it is formed after releasing stored energy generated as the cutting edge passes the metal. Additionally, some researchers [1] referred

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formation of residual stresses for three reasons. Firstly, mechanical, due to plastic deformation of the metal. Secondly, thermal, due to temperature difference resulting from heating of the part. Finally, structural, owing to the phase transformations that may happen. According to some others [8], it is a combination of thermal and mechanical causes.

Several studies were conducted so far to examine the effect of changing turning parameters on the created surface residual stresses. Those yielded to different, sometimes even opposing conclusions. According to a study was done on AISI 4340 steel type [5], the increment of cutting speed in the 200–300 m/min range resulted in more compressive tangential and axial residual stresses. The same result was shown by another study [9] carried out on AISI 316L steel type in the 75–125 m/min zone. However, the authors of [10] found the opposite with the same steel type in the 80-200 m/min range. Scholars in a study [11] have examined the effect of cutting speed in a wide range of inspections in a bainitic steel. They have concluded that increasing cutting speed shifts tangential and axial residual stresses towards more compressive-in-nature in the 50–230 m/min range, while in the 230–999 m/min region, the opposing effect was observed. Authors of [12] claim that the effect of cutting speed on tangential and axial stresses in 18MnCr5 case-carburized steel is controversial in the 110–230 m/min domain.

Likewise, controversial results were found about the effect of turning feed. The results of a study was done on AISI 52100 steel [13] show that as feed increases in the 0.28–0.56 mm/rev region, residual stresses tend to be more compressive. For the same steel, another study [14] found that this is true for the depth stress profiles in the 0.1–0.5 mm/rev range, but for the surface, results were debatable. It is worth mentioning that they have examined the depth profile only in singular points on the surface. On the other hand, the opposite effect was observed by another study [15] with the same type of steel (AISI 52100) for axial stresses in the 0.05–0.15 mm/rev domain, also by a study was done on 18MnCr5 steel [12], and on 39NiCrMo3 steel [16] in the 0.05–0.25 mm/rev range.

Regarding tool nose radius, lack of agreement can be found in the available literature. The scholars in [15] and [13] have observed that decreasing tool nose radius shifts stresses towards more tensile in AISI 52100 steel, whereas in [16] and [17], researchers have found the opposite in 39NiCrMo3 and JIS SUJ2 steels, respectively. Finally, study [12] revealed that the effect of tool nose radius on tangential and axial stresses in 18MnCr5 steel is opposing.

From the previous discussion, it is clear that despite many studies were conducted to investigate the relationship between the different turning parameters and their effect on surface residual stresses, still this area has some ambiguity which needs more clarification, not only because of some mismatching results but also because of other reasons. It was clearly shown that changing only one turning parameter can have an opposing effect on residual stress, depending on the range of inspection and type of steel. The previous studies show the effect of changing only one turning parameter, or rarely two. In the present study, cutting speed, feed, and tool nose radius were varied, and the formed residual stresses on the surface were investigated in a comprehensive manner. In addition, all previous studies that were conducted on bearing steels were carried out after hard turning, whilst this research was carried out after the soft turning of 100CrMnSi6-4 bearing steel since sometimes it is needed to firstly turn the ring and then separate it from its mother part and then to harden it. Finally, this research is the first one that puts light on the correlation between turning parameters and the formed surface residual stresses after the turning of this type of bearing steel.

2. EXPERIMENTAL PROCEDURE

The examined bearing rings were made of 100CrMnSi6-4 bearing steel after soft turning. Eight rings were turned with different parameters. In this research, different cutting speeds v_c, feeds f and cutting tool nose radii r_ε were applied. Table 1 shows the values of these parameters for each sample. For the whole samples, the radial depth of cut was 0.5 mm.

Table 1. Details of turning parameters

Sample No.	$\boldsymbol{v_c}$ m/min	$\boldsymbol{f}$ mm/rev	$\boldsymbol{r_\varepsilon}$ mm
1	105	0.1	0.4
2	300		
3	105	0.3	
4	300		
5	105	0.1	0.8
6	300		
7	105	0.3	
8	300		

Tangential (speed direction) and axial (feed direction) residual stress components were measured at eight different locations along the circumference of each ring. These locations were marked as A to H, and the distances between these points were equal. The residual stresses were measured using the $\sin^2\psi$ method with a Stresstech G3R type centreless diffractometer, equipped with Cr X-ray source. For measurements, the {211} reflections were measured. During the measurements, a collimator of 3 mm diameter was used

3. RESULTS AND DISCUSSION

3.1. TANGENTIAL STRESS COMPONENTS

Figure 1 summarizes the measured tangential stress values corresponding to different turning conditions. It can be seen that only tensile stresses were measured, but their magnitude strongly depend on all turning parameters. It is generally observed that as turning speed is increased, tangential tensile stresses increase. However, the magnitude of stress increment depends on the other turning conditions. At 0.1 mm/rev feed and 0.4 mm tool nose radius, stresses are at around 250 – 300 MPa for the 105 m/min cutting speed and they are above 400 MPa for the 300 m/min speed. At the 0.1 mm/rev feed and 0.8 mm tool nose radius, stresses of 300–350 MPa shift to ~450 MPa as cutting speed is increased from 105 m/min to 300 m/min speed. For the 0.3 mm/rev feed, at 0.4 mm and 0.8 mm tool nose radius, stresses are at around 450 MPa and slightly below or equal to 500 MPa for the 105 m/min cutting speed, respectively, while they are between 500 and 550 MPa and are somewhat above 500 MPa for the 300 m/min speed, respectively.

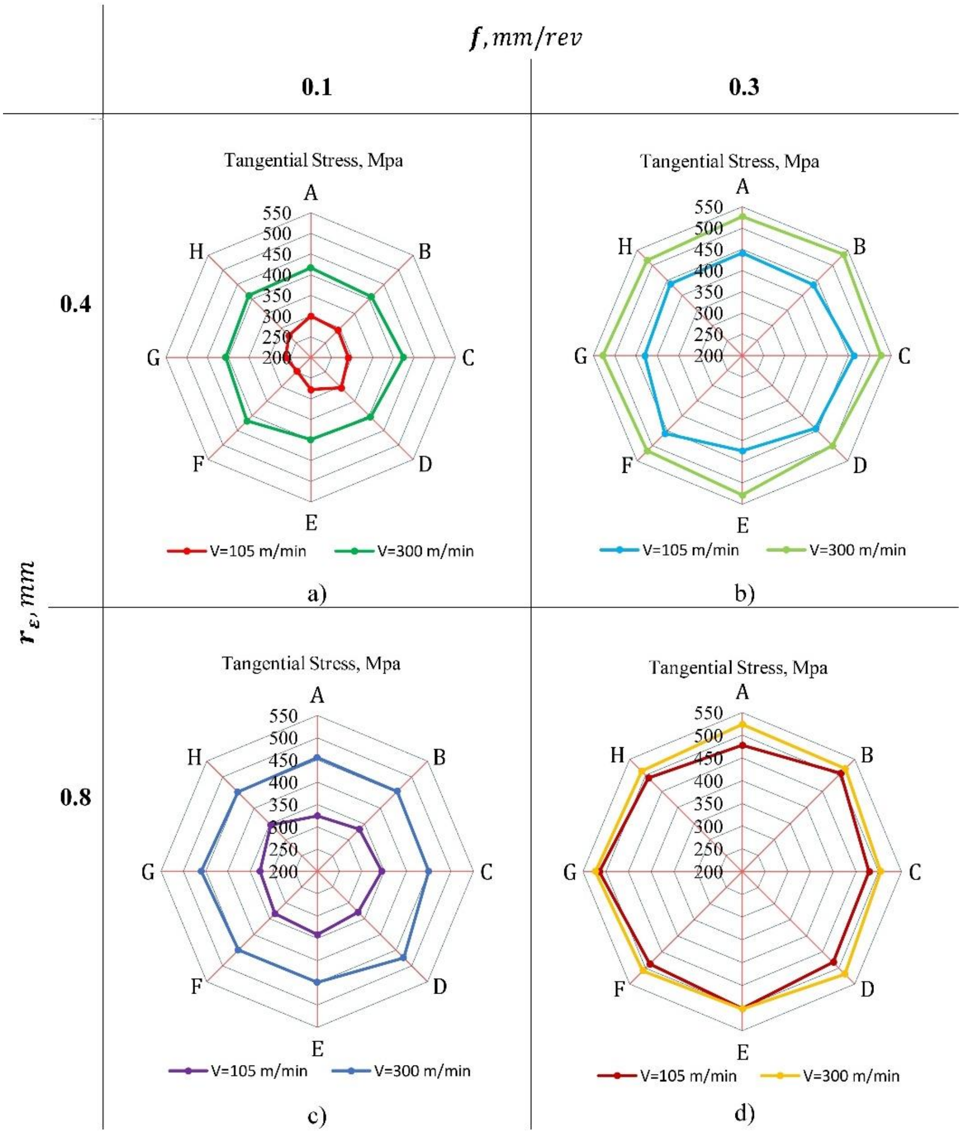

Fig. 1. Tangential residua stresses measuring along the circumference of tapered roller needle bearing rings made of 100CrMnSi6–4 bearing steel

It is also apparent from the results that for every examined turning condition, tangential tensile stresses increase with increasing turning feed. For the 0.4 mm tool nose radius, at the 105 m/min and 300 m/min cutting speeds, stresses of 250–300 MPa increase to ~450 MPa and stresses of ~400 MPa shift to 500–550 MPa, respectively, as feed is increased from 0.1 mm/rev to 0.3 mm/rev. At the 0.8 mm tool nose radius and 105 m/min speed, measured stresses are between 300 and 350 MPa, and they increased to ~500 MPa with increasing feed from 0.1 mm/rev to 0.3 mm/rev. At the same tool nose radius, and at the 300 m/min cutting speed, stresses of 450 MPa shift to ~500 MPa as feed is increased from 0.1 mm/rev to 0.3 mm/rev.

Regarding tool nose radius, it can be observed that under most examined conditions, larger tangential tensile stresses were formed with larger tool nose radius. At the 0.4 mm tool nose radius and 0.1 mm/rev feed, at 105 m/min and 300 m/min cutting speeds, stresses are between 250 and 300 MPa, and are around 400 MPa, respectively, and increased to 300–350 MPa and around 450 MPa, respectively, as tool nose radius is increased to 0.8 mm. For the 0.3 mm/rev feed, at 105 m/min and 300 m/min cutting speed, stresses are around 450 MPa and 500 MPa at the 0.4 mm tool nose radius, respectively, and shifted to slightly below 500 MPa and to 550 MPa as tool nose radius is increased to 0.8 mm.

3.2. AXIAL STRESS COMPONENTS

Figure 2 shows the results of stresses measured in the axial (feed) direction corresponding to different turning conditions. It can be seen that tensile stresses were formed, but the magnitude of those stresses varies strongly (below 100 to 600 MPa) depending on the combination of turning parameters. It can be observed that cutting speed has small effect on the residual stress values. Increasing cutting speed does not influence the axial stresses, or, under some turning conditions, it decreases the magnitude of axial tensile stresses. At the 0.1 mm/rev feed and 0.4 mm or 0.8 mm tool nose radius, increasing cutting speed does not affect the stresses. At the 0.3 mm/rev feed and 0.4 mm tool nose radius, axial stresses decrease from 300 MPa to 200 MPa as cutting speed is increased from 105 m/min to 300 m/min. At the same feed with the 0.8 mm tool nose radius, stresses dropped from 600 MPa to 500 MPa with increasing the cutting speed.

Concerning the effect of turning feed, it is generally observed that increasing feed increases the axial tensile stresses. At the 0.4 mm tool nose radius and 105 m/min cutting speed, the axial stresses increased from below 100 to 300 MPa, while at the 300 m/min speed, they increased from 0 to 200 MPa as feed was increased from 0.1 mm/rev to 0.3 mm/rev. At the 0.8 mm tool nose radius, for the105 m/min and 300 m/min cutting speeds, axial stresses are between 250 and 300 MPa, and increased to 600 MPa and 500 MPa with increasing feed from 0.1 mm/rev to 0.3 mm/rev, respectively.

Finally, increasing tool nose radius has increased the axial tensile stresses for the all examined conditions. At the 0.1 mm/rev feed, for both 105 and 300 m/min cutting speeds, axial stresses have increased from below 100 to 200–300 MPa with increasing the tool nose radius. At the 0.3 mm/rev feed, for the lower and higher speeds, stresses have increased from 300 MPa and 200 MPa to 600 MPa and 500 MPa with increased tool nose radius, respectively.

In order to get a comprehensive relation about the relationship between the examined turning parameters and the developed residual stresses, Fig. 3 shows a three-dimensional plot of tangential and axial stresses averaged along the circumference of the rings as a function of the examined turning variables. The following conclusions can be drawn from this plot.

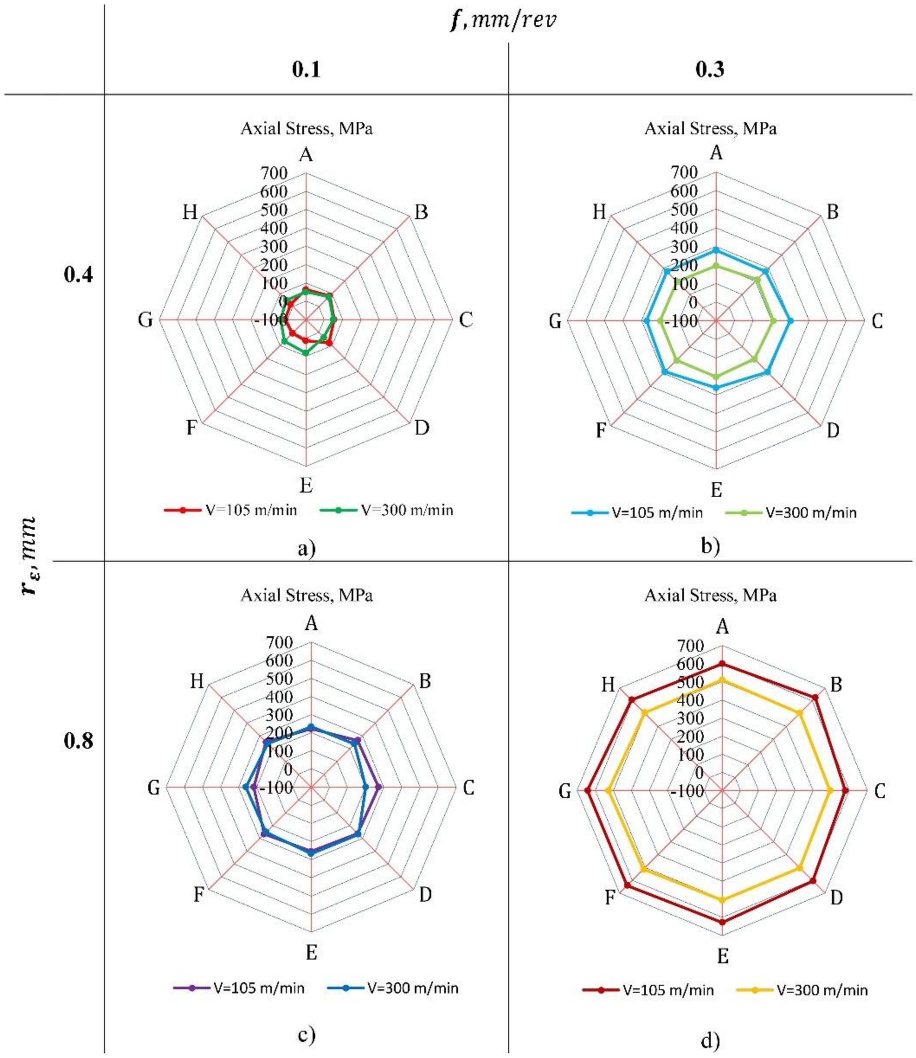

Fig. 2. Axial residua stresses measured along the circumference of tapered Roller needle bearing rings made of 100CrMnSi6–4 bearing steel

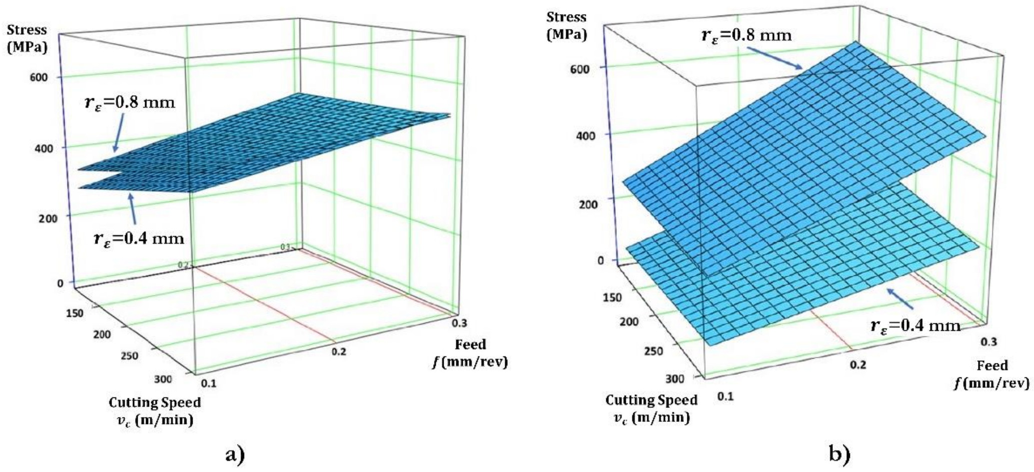

Fig. 3. Relationship between turning parameters and a) tangential, b) axial residual stresses of tapered roller needle bearing rings of 100CrMnSi6–4 bearing steel

Firstly, increasing cutting speed increases tangential tensile stresses. This effect is more pronounced at the smaller feeds for both examined tool nose radii. On the other hand, increasing cutting speed decreases axial tensile stresses. This effect is stronger at the larger feeds and in case of larger tool nose radius. Therefore, it can be concluded that increasing cutting speed shifts tangential stresses towards more tensile, while axial stresses towards more compressive. The magnitude of this shift depends on both feed and tool nose radius. Secondly, increasing feed increases the magnitude of developed tangential and axial tensile stresses for all examined cutting speeds and tool nose radii combinations, but in the case of using the higher tool nose radius, it has more effect on increasing stresses in the axial direction. Finally, for all examined turning conditions, larger tangential and axial tensile stresses developed with increasing tool nose radius, but its effect is larger in the case of created axial stresses.

4. CONCLUSIONS

In this study, the combined effect of changing turning speed, feed and tool nose radius on surface residual stresses was investigated during turning of 100CrMnSi6-4 bearing steel. It was shown that the effect of changing a given turning parameter on the developed residual stresses also depends on the other turning parameters. This was observed even when the examined turning parameter was changed between only two values. Thus, generally applicable conclusion cannot be safely drawn about the effect of changing one turning parameter on residual stresses. Instead, such statements must be connected to the other examined specific processing parameters. To determine the optimal turning conditions from the point of view of residual stresses, all variable parameters were examined thorough the study. According to the performed measurements, less tensile stresses can be achieved after turning of 100CrMnSi6-4 bearing steel with 0.4 mm tool nose radius, 0.1 mm/rev feed and 105 m/min cutting speed.

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