IMPLEMENTATION OF COLD ROLLING PROCESS IN BEARING INDUSTRY

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This paper deals with implementation of various strategies in production of bearings and their influence on the consecutive operations. Shaping of bearings via cold rolling in compared with conventional process usually employed in bearing industry based on machining cycles on hot rolled parts. Such aspects as structure, stress state before and after heat treatment, rings deformations after heat treatment (hardening and consecutive annealing) and cutting forces during hard turning are investigated. The results show that investigated strategies produce quite different stress state and the corresponding deformation during heat treatment. Deformations of rings due to heat treatment regime cause significant instability of cutting force components. On the other hand, influence of different strategies on stress state after heat treatment as well as hard turning is minor.

KEYWORDS

bearing, cold rolling, residual stresses, structure

1. INTRODUCTION

Production of bearings usually consists of consecutive operations when primary shape of the ring is obtained via machining followed by hardening. Grinding cycles (or combination of hard turning, grinding and superfinishing) are employed after hardening to obtain required dimension and shape precision of rings as well as surface roughness. However, other strategies are also investigated and considered to attain time and corresponding economy benefits [Neslusan 2014] [Karpuschewski 2013]. In the recent years some machining cycles are sometimes substituted by other processes. Cold rolling before heat treatment is a strategy of the ring shaping used a little and waiting to be proved. The main advantages of such strategy can be viewed in reduction producing time and avoiding of chips resulting in the notable corresponding economy and ecology benefits. Implementation of cold rolling brings 12% increase in productivity before heat treatment and 25% reduction of costs associated with material purchasing (valid for rings investigated in this study). On the other hand, cold rolling process produces parts of altered stress and structure state as significant aspects influencing the consecutive operations and functionality of components in use. It is well known that regime of heat treatment (HT) in bearing industry significantly affect ring deformations [Jech 1968]. However, these deformations are also a function of stress and microstructure before hardening [Dubec 2013]. Being so, final dimension and shape precision as well as surface roughness has to be achieved via consecutive grinding cycles (or combination of hard turning, grinding and superfinishing). Rings deformations strongly affect instability of final cycles (mainly hard turning or rough grinding) and thickness of the layers which should be removed in the final stages of production [Neslusan 2010]. For this reason all cycles before HT as well as regime of HT are closely related to production times and the corresponding economy. Implementation of new strategies in production of bearings should be carefully considered and investigated from economy as well as technical aspects since bearings play a key role in functionality of machines. Being so, this paper compares two different strategies such as conventional turning and cold rolling cycles in bearing production before HT (hardening followed by annealing) and their influence on:

- microstructure before and after HT (as well as after hard turning),
- rings deformations expressed in their ovality,
- stress state before and after HT as well as hard turning,
- instability of hard turning cycles after heat treatment due to rings deformations.

2. EXPERIMENTS

Experiments were carried out on bearing steel 100Cr6 before HT as well as after HT (HT in this study represents hardening followed by the consecutive annealing). Hardness of the rings after HT is about 61 HRC. The samples (the inner ring of a bearing) of external diameter 140,4 mm, internal diameter 125,54 mm with two raceways of width 12 mm (total width (33,4 mm) were produced via machining (mainly turning) and cold rolling.

Turned rings: annealed at 810 ºC and slowly cooled to 550 ºC, turned on at the following conditions – v_c = 170 m.min^{-1}, f = 0,3 mm, a_p = 2 mm, cutting insert DNMG 160612-TF, coolant Ecocool SNK GTG 5% concentration, initial dimensions 143x122x36,5 mm.

Cold rolled rings: rolled on URWA 250 under the following conditions – rolling force 390 kN, n = 350 min^{-1}, feed 1,1 mm, rolling time 6 seconds, initial dimensions 89,2x68,7x32,3 mm.

The rings were heated to austenitizing temperature 840 ºC for 30 minutes and quenched in the oil Durixol V35C of temperature 60 ºC. Thereafter, the rings were tempered in the furnace at temperature 160 ºC for 2 hours. The rings (their raceways) after HT were hard turned by the use of cutting inserts DNGA 150408 made of CBN (with TiN coating), VB = 0,07 mm. Cutting conditions as follows: v_c = 100 m.min^{-1}, f = 0,09 mm, a_p = 0,5 mm, dry machining, lathe SUI 40.

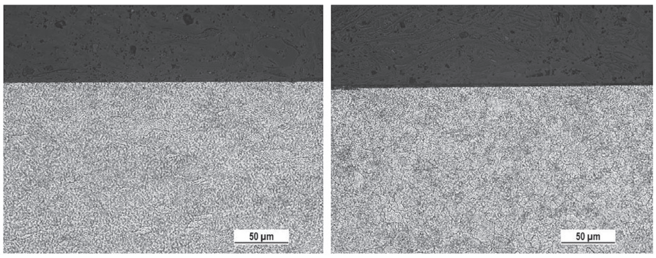
Two series as turned and cold rolled were produced to investigate some aspects of producing cycle. Each series represents 100 inner rings. Measurement of ovality before and after HT was carried out on all rings whereas measurement of residual stresses, structure observation and hard turning was investigated on limited number of rings (4 rings of average ovality after HT as cold rolled, 4 rings o maximum ovality after HT as cold rolled, 4 rings of average ovality after HT as turned, 4 rings o maximum ovality after HT as turned).

Ovality was analyzed by the use of measures UD 400 especially modified for such purpose. Components of cutting force during hard turning were measured by the use of KISTLER dynamometer at sampling frequency 2kHz. Signals were amplified, A/D converted and fed to software DasyLab 3.5. As an example only passive component Fp of cutting force is reported in this study. Samples for metallographic observation were routinely prepared by cold sectioning, hot moulding, grinding, polishing and etching (5% Nital etch for 10 seconds). Microstructure was observed in the direction of cutting speed. Residual stresses were measured by mechanical method [Neckar 1985] based on eletrolythical etching (4 hours, 20 % concentration of H_2SO_4 – electrolyte, 5V and 6A) machined surface and simultaneous measurement of a ring deformation. The details about principle, mathematic apparatus and measuring unit can be found in [Neckar 1985].

3. RESULTS OF EXPERIMENTS

3.1 Microstructure and stress state before HT

Micrographs illustrated in Figure 1 show that near surface as well as subsurface region of turned sample in not visible altered. Machined surface does not exhibit any structure transformations or preferential orientation of ferrite matrix and microstructure consist of equiaxed ferrite grains (+primary carbides regularly distributed in the matrix). On the other hand, cold rolled sample exhibits remarkable preferential orientation of ferrite matrix in direction of cold rolling whereas carbides retain in their original shape and distribution as that before cold rolling. The grains are strained in the same direction except the near surface region containing stagnation zone due to friction between the surface and moulding ring. Also stress state is quite different. Turned surface contains compressive stresses in the near surface region due to existence of a certain cutting edge radius (as well as developed VB) and the flow of certain volume of material under the cutting edge. Compressive stresses are followed by subsurface tensile stresses as a region in which temperature effect dominate over severe plastic deformation. Finally, bulk (deeper regions) contains compressive stresses of magnitude about 35 MPa originating from previous hot rolling process (as received from raw material supplier), see Figure 2. Cold rolled surface also contains compressive stresses in the near surface region. However, bulk contains tensile stresses of magnitude about 100 MPa, see Figure 2. Figure 2 shows that either turning or cold rolling strategy produce compressive stress in the near surface. Remarkable difference can be found in stresses in the bulk. While ferrite matrix dynamic recovery produces low compressive residual stresses after hot rolling, cold rolling initiates mainly tensile residual stresses of medium magnitude. Microhardness readings exhibit only a little increase of microhardness in the near surface region after turning (about 240 HV0,05 whereas bulk microhardness is 200 HV0,05). On the other hand, cold rolled stagnated zone gives 300 HV0,05 and deeper regions 280 HV0,05 (due to increased dislocation density).



a) as cold rolled b) as turned

Figure 1. Micrographs of near surface region before HT

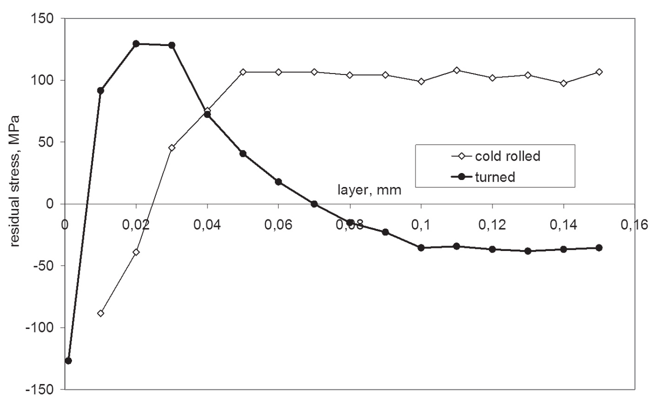
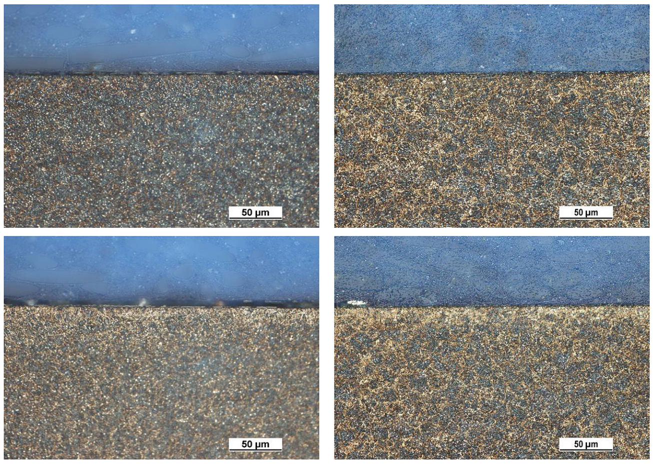


Figure 2. Residual stress state before HT

3.2 Microstructure and stress state after HT

Figure 3 illustrates microstructure after HT. Micrographs as well as stress state after HT indicate that application of the different strategy for bearing ring shaping does not significantly affect martensite transformation expressed in terms of martensite matrix appearance or magnitude of residual stresses. Difference in stress profiles after HT is minor since residual stresses initiated by the previous machining or/and rolling are released during heating on austenitizing temperature. Both series exhibit variations in microstructure (appearance of dark and light layers/zones). Carbides embedded in the martensite matrix retain in their original shape and distribution as that before HT.



a) as cold rolled b) as turned

Figure 3. Micrographs of near surface region after HT

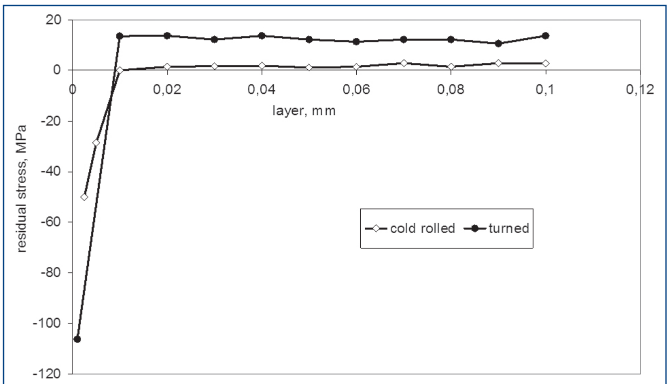


Figure 4. Stress state after HT

Martensite structure of 100Cr6 appears usually dark. However white strips appearing in the near surface region (in the case of both series) followed by dark zones indicate variation in microstructure (its properties) and the corresponding near surface hardness.

3.3 Ovality of rings after HT and hard turning dynamics

Significant differences between two strategies can be found in the shape precision (ovality) of the rings measured on the raceways before HT. Figure 5 shows that ovality of the rings obtained via cold rolling process is more that twice as higher as opposed to turning process. Moreover, ovality before HT for turned series can be found in the range of 0,014 to 0,12 mm whereas cold rolled rings ovality is in the range of 0,09 to 0,17 mm. HT produces remarkably higher ovality of ring for both series due to thermally initiated deformations originating from structure, stress and dimension non homogeneities within ring diameter. Figure 5 shows that average ovality of the rings is not sensitive to previous strategy as those investigated in this study. Average ovality after turning and the consecutive HT is 0,29 mm whereas cold rolling followed by HT gives average ovality 0,32 mm. On the other hand, ovality after HT for turned series can be found in the range of 0,03 to 0,65 mm whereas cold rolled rings ovality is in the range of 0,1 to 0,89 mm.

Remarkable rings deformations expressed in term of their ovality significantly contribute to instability of rough hard turning cycles. Figure 6 illustrates the raw records of passive component of cutting force Fp. First pass of the tool (turning of ring raceway with ovality after HT) exhibits strong instability (fluctuation of F_p) originating from:

- variable cutting depth due to ring ovality,
- non homogeneity of structure after HT as stated above,
- chip segmentation (however dynamometers are not capable to detect the real force oscillation because segmentation frequencies lie above 10 kHz [Neslusan 2015]).

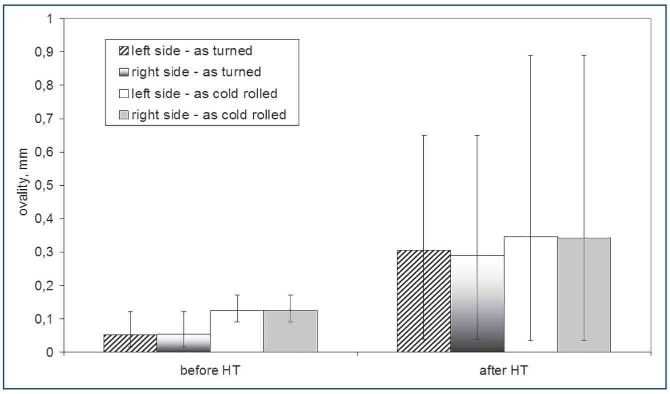


Figure 5. Ovality before and after HT (left side = left ring raceway, right side = right ring raceway)

Second pass represents the consecutive cutting on the same ring raceway when ovality originating from HT was removed via previous cutting cycle. Figure 6 illustrates reduced oscillation of F_p and more stable cutting process in which chip segmentation takes major role. Figure 7 compares static and dynamic components (expressed in its rms value) of F_p for two strategies as well as hard turning with and without ovality after HT. Multiple measurements (on the ring of comparable ovality) indicate that hard turning of the raw surface (with ovality originating from HT) initiate higher dynamic components of cutting force (compared with dynamic components during the second pass). On the other hand, hard turning of rings without remarkable ovality gives higher static components and reduced process dynamics. Multiple measurements also indicate that different strategies applied before HT do not take significant role in neither hard tuning dynamics expressed in rms values nor static components expressed in F_p (taking into account the dispersion of multiple measurements indicated in Figure 7).

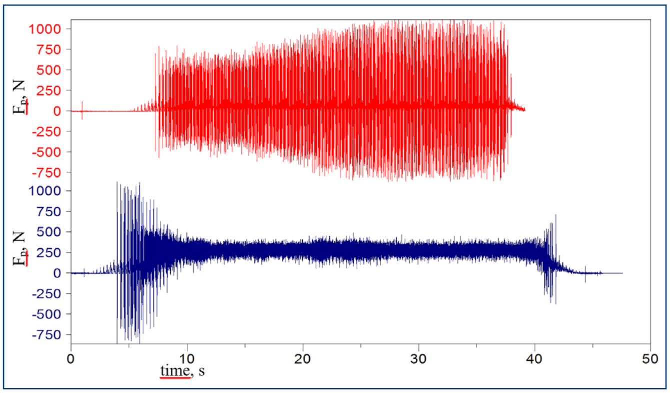


Figure 6. Record of passive component F_p of cutting force during hard turning, red – first pass (turning of the ring with ovality 0,6 mm after HT) blue – second pass (turning without ovality)

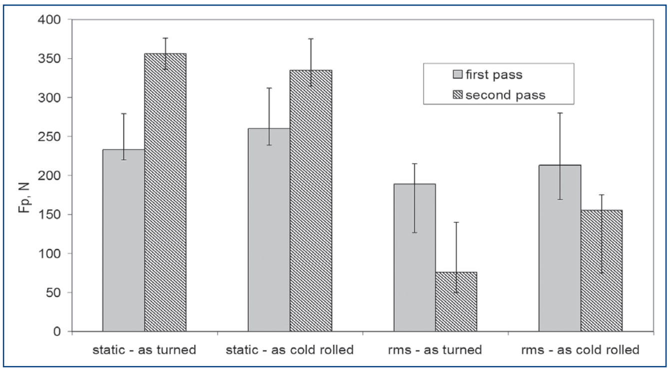


Figure 7. Static and rms values of F_p during hard turning, as turned – ovality after HT 0,6 mm, as cold rolled – ovality after HT 0,32 mm

3.4 Microstructure and stress state after hard turning

Rough hard turning is usually followed by grinding. In some case hard turning can substitute final grinding cycles. The main difference between rough and fine hard turning can be found in cutting depth. However, surface integrity expressed in terms of residual stress state as well as microstructure is not sensitive to cutting depth because increasing cutting depth load mainly rake face of the tool whereas tool – workpiece contact stays nearly untouched [Barbacki 2002]. Figures 8 and 9 show that also strategy in rings shaping (turning and cold rolling) does not take any role in residual stress state as well as microstructure. Near surface region contains thin and discontinuous white layer of comparable thickness. White layer is due to heating this region above austenitizing temperature followed by rehardening effect during rapid self cooling. Martensite matrix in the near surface region is preferentially oriented in the direction of cutting speed together with carbides severely strained in the same direction. Residual stress profiles contain thin near surface region of compressive stresses followed by region of tensile stresses. Finally, deeper thick layers contain compressive stresses exceeding -300 MPa.

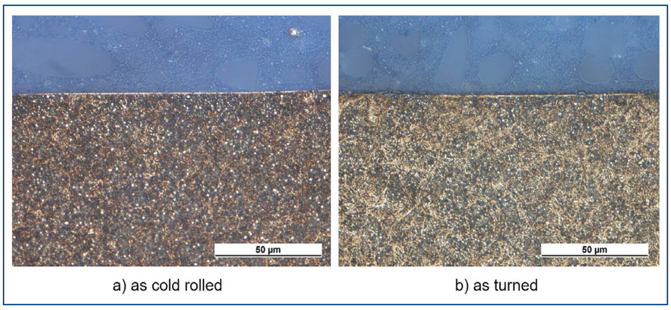


Figure 8. Micrographs of near surface region after hard turning

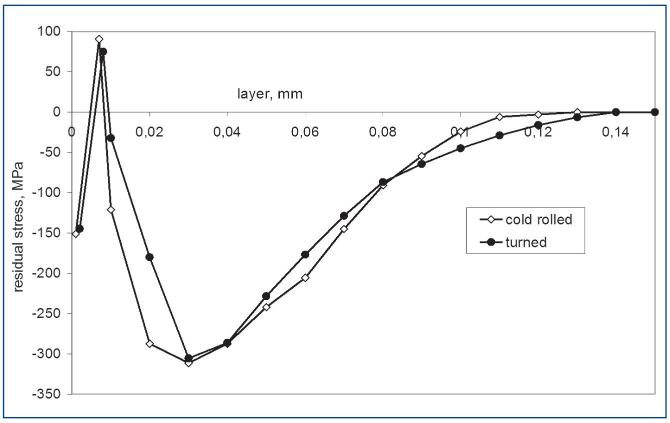


Figure 9. Stress state after hard turning

4. CONCLUSIONS

Quality of bearings is crucial for functionality of machines in operations. This study indicates that application of two different strategies employed before HT does not significantly affect surface integrity expressed in terms of stress state or microstructure. On the other hand, progressively developed flank wear VB should in turning strategy should considered and investigated as a aspect strongly affecting surface state [Dubec 2012] whereas in the case of cold rolling does not. Further investigations proved that both strategies produce bearing rings of comparable quality expressed also in terms of dimension and shape precision after hard turning even grinding cycles. Only difference of cold rolling process (as opposed to turning), from the point of view of consecutive manufacturing process, can be found in higher static components of cutting force and gentle increase of rings ovality (respective the range in which their occur). Being so, substitution of conventional turning by cold rolling seems to be promising concept due to possible time savings and the corresponding economy and ecology benefits.

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