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RESEARCH

Neutral Radius Value Determination by Numerical Simulation Method at Ring Upsetting Test

Ring upsetting represents a basic operation for bulk forming process and has particular significance since it is used for contact friction determination.
At ring upsetting by flat dies, metal flow depends upon tribological conditions present at contact surface. Thereby, two variants of metal flow are possible:
a) two-way flow from neutral radius that is present at lower friction coefficient values, followed by ring's inner radius reduction and ring's outer radius increase. In such circumstances, neutral radius is found between inner and outer radius.
b) one-way flow that occurs at higher friction coefficient values, where neutral radius is lower than ring's inner radius.
This paper is presenting the results of determination of relation between neutral radius value and friction coefficient. Such relation is determined by numerical simulation, by using Simufact.Forming software. Experimental verification of neutral radius position is conducted by metallographic analysis, for two friction coefficient values. Friction coefficient values are determined by ring upsetting by using dies, where in one case of ring upsetting, contact surfaces were ion implanted with nitrogen

Keywords: *Neutral radius, Friction coefficient, Ring upsetting, Ion implantation.*

1. INTRODUCTION

For a correct tool design it is necessary to analyse the stresses at the tool–workpiece interface with a high degree of accuracy in order to use the process at the limit and to avoid early tool damage. In this analysis friction plays a central role because it is strongly influenced by the existing distribution of the contact variables at the tool–workpiece interface. Moreover, these contact conditions have a great influence on the material flow [1].

One of the most essential problems of technology of plasticity are metal flow across die and cavity filling. These problems are especially associated with tribological state that is present on contact surface between die and workpiece. Since plastic deformation take place in a state of a high contact stresses, which can result in a high tangential stresses too, it is very important to lower the friction coefficient. In this manner it is possible to shape complex parts and lowers the amount of required operations and production cost.

As universal method for friction coefficient measurement in bulk metal forming processes, ring upsetting by flat plates (dies) have been used [2, 3, 4].

2. MATERIAL FLOW AT RING UPSETTING

Key phenomenon required for understanding the subject of wear and friction is material flow across die's surface during plastic deformation. In this paper material flow is analyzed through ring upsetting process by flat dies since upsetting is also used for friction coefficient determination. Material flow phenomenon is investigated by direct measurement of microstructural changes in workpiece at deformation process. Nowadays, modern software packages are also being used for material flow process simulation.

Ring upsetting represents a fundamental operation of bulk forming process and it is a phase in multiphase plastic forming process. This process is

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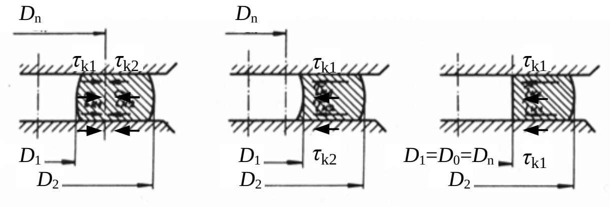
particulary interesting from an aspect of possible material flow variants, which depends on a friction coefficient.

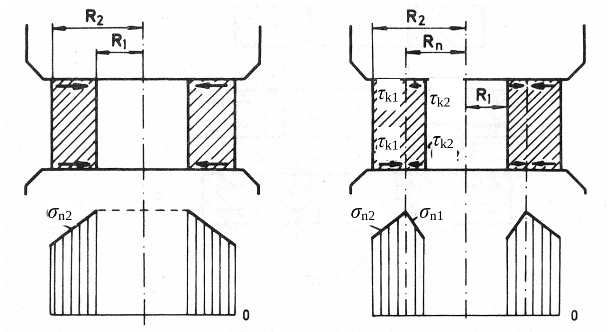
According to figure 1 there are three types of material flow at ring upsetting.



a b c

Figure 1. Types of material flow in ring upsetting [5]

In first type (fig. 1a), material flows in opposite directions respecting neutral radius R_n. Inner diameter decreases D_1, while outer diameter increases D_2. In this case neutral diameter is within the range $D_1<D_n<D_2$. Direction of tangential stress is opposite of material flow direction which affect normal contact stresses too (fig. 2b). This type of material flow occurs at lower friction coefficient values.



a b

Figure 2. Contact stresses distribution depending on material flow [5]

In second type of material flow, both, inner D_1 and outer D_2 diameter increases. In this case, neutral diameter is smaller than inner diameter $D_n<D_1$ (fig. 1b). Contact stresses distribution is shown on figure 2a.

Third type of material flow is featured by one-way material flow with no change of inner diameter. In this case the inner diameter is equal to the neutral diameter $D_1=D_n$.

Second and third type of material flow appears with higher values of friction coefficient.

Based on the presented three types of material flow at ring upsetting it is possible to conclude that the direction of material flow is characterized by the contact friction coefficient value. Furthemore, nature of material flow is also defined by neutral radius. Its magnitude can be determined theoretically, numerically and experimentally.

3. RING UPSETTING EXPERIMENT

Contact friction coefficient was determined experimentally by ring upsetting method (fig. 3).

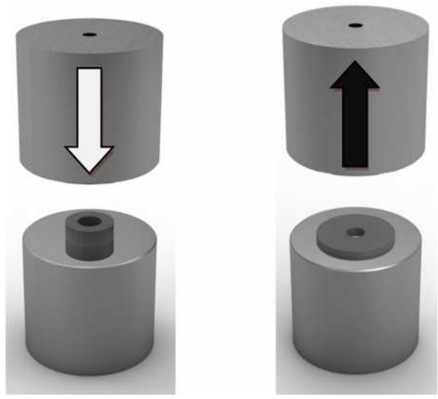


Figure 3. Ring upsetting method

Method consists of establishing the dependence between deformation of inner ring's diameter and ring's height. This dependence is taken into etalon chart and compared with existing within the chart.

Ring upsetting has been performed incrementally, with a height deformation around 10%. After each upsetting stage ring's dimensions were measured. Incremental upsetting has been carried out until total deformation of the ring's height has reach around 70%.

Once the ring upsetting has been completed deformation of the ring's inner diameter and deformation of the ring's height has been calculated for each upsetting increment. By connecting all the pairs of height and inner diameter deformation curve was defined.

In order to find the friction factor for the completed upsetting process it is necessary to compare the curve with an existing ones from the etalon diagram.

Ring upsetting has been carried out with two different pairs of dies. One pair of dies has been grinded, polished and ion implanted with $2 \cdot 10^{17}$ N^+ 50 keV, while another pair of dies has not been ion implanted. Dies were made of X210Cr12 cold work tool steel (Č.4150) with dimensions ø50×45 mm.

Rings were made of Ck15 unalloyed carbon steel (Č.1221) with initial dimensions D_2:D_1:h=18:9:6 mm. Hardness of the dies was 58+2 HRC, while hardness of the ring upset with nonimplanted dies was 167 HV-10 and hardness of the ring upset with implanted dies was 161 HV-10.

4. RING UPSETTING SIMULATION BY FINITE ELEMENT METHOD

After friction factors were obtained from ring upsetting, their values were used for ring upsetting simulation. Ring upsetting simulation was performed by Simufact.forming software that is based on FEM. In forming processes this kind of software can provide detailed information about stresses, strains, material flow, friction factors and many more.

Simulation was carried out with following input data which accurately as possible describes actual experimental conditions:

- simulated process: cold upsetting,
- analysis type: 2D, axisymmetrical,
- initial workpiece dimensions: D_2:D_1:h=18:9:6 mm,
- workpiece material: Ck15 (Č.1221), flow curve σ_{avg}=max(0, 276.44+397.715·$\varepsilon_{avg}^{0,317096}$,
- finite element size: 0,1 mm, rectangular shape,
- die dimensions: ø50×45 mm,
- die material: rigid body,
- die, workpiece and environment temperature: 20°C,
- friction type: constant (plastic shear friction),
- friction factors: m=0.11 (for implanted dies) and m=0.15 (for nonimplanted dies),
- upper die stroke: 4.2 mm.

5. RESULTS

5.1 Ion implantation simulation by SRIM software

In order to ensure successful ion implantation into X210Cr12 steel, SRIM simulation software was used to evaluate the effect of $2 \cdot 10^{17}$ N^+ 50 keV ion implantation into die's surface. As it can be seen from figure 4, ion implantation depth was around 100 nm. For the convenience, SRIM simulation on figure 4 was completed with 10000 ions.

Based on the results of simulation, ion implantation of the dies has been carried out in Institute of Nuclear Sciences "Vinča".

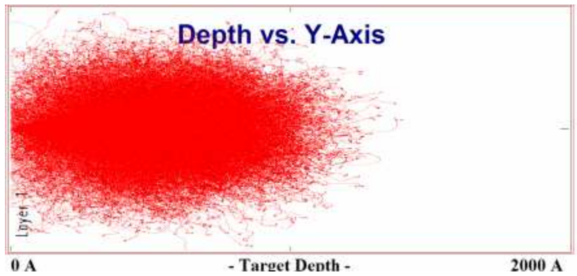


Figure 4. SRIM simulation of ion implantation into steel

5.2 Ring upsetting – contact friction coefficient

Figure 5. shows comparison of friction factors obtained from a ring upsetting experiment.

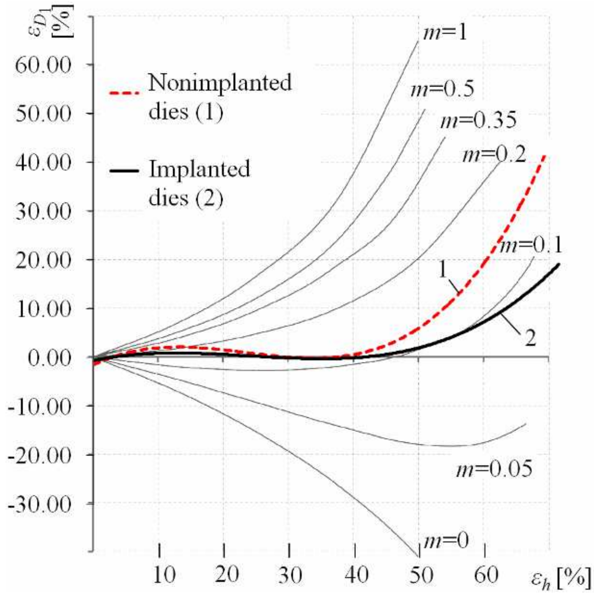


Figure 5. Comparison of friction factors for rings upset with implanted (2) and nonimplanted dies (1) [4]

Table 1. shows friction factors and friction coefficients values obtained in ring upsetting experiment.

Table 1. Friction factors and friction coefficients for rings upset with implanted and nonimplanted dies

Dies	Friction factor (m)	Friction coefficient (μ)
Nonimplanted	0.15	0.087
Implanted	0.11	0.064

5.3 Contact stress distribution

Figures 6. to 8. display tangential contact stress distribution across ring’s surface obtained from Simufact.forming simulation at ring upsetting with nonimplanted dies.

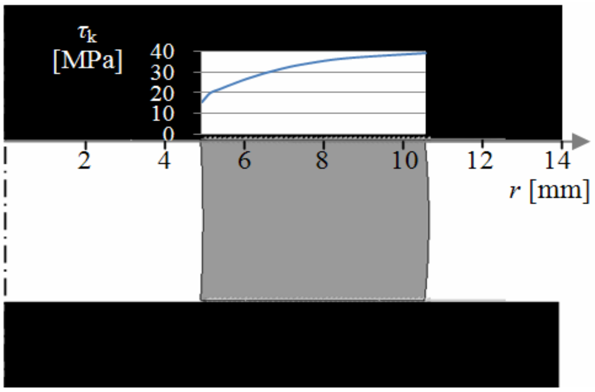


Figure 6. Tangential contact stress distribution, die stroke 1.72 mm

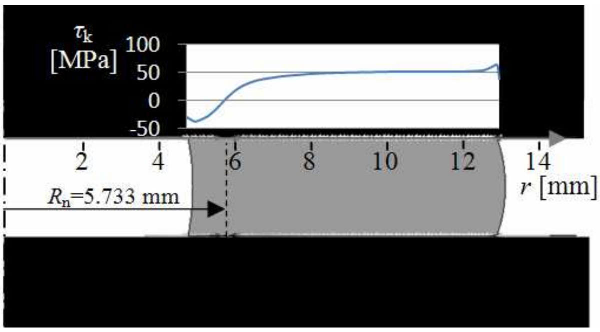


Figure 7. Tangential contact stress distribution, die stroke 3.4 mm

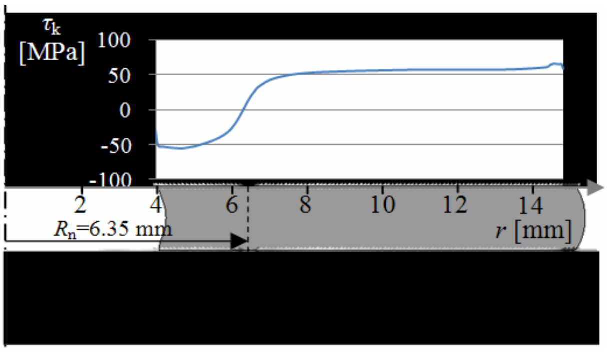


Figure 8. Tangential contact stress distribution, die stroke 4.2 mm

Figures 9. to 11. display tangential contact stress distribution across ring’s surface obtained from Simufact.forming simulation. Ring has been upset with implanted dies.

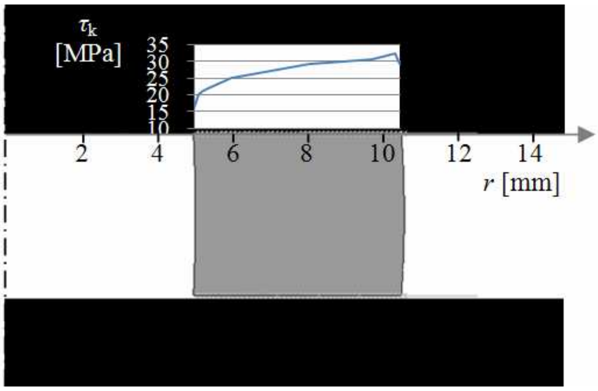


Figure 9. Tangential contact stress distribution, die stroke 1.72 mm

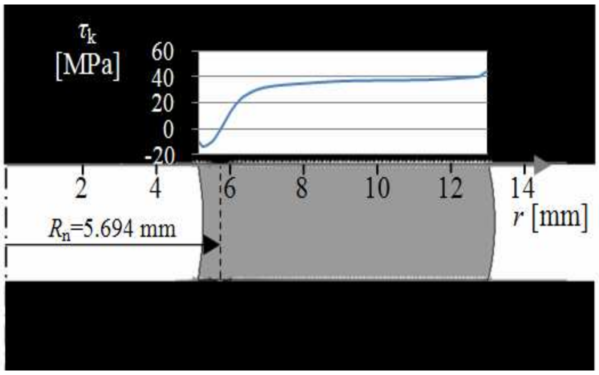


Figure 10. Tangential contact stress distribution, die stroke 3.4 mm

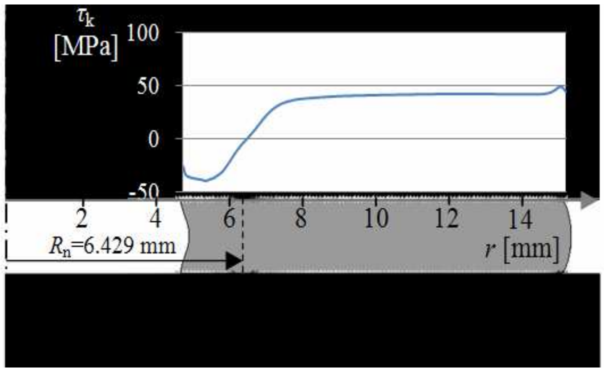


Figure 11. Tangential contact stress distribution, die stroke 4.2 mm

Figures 12. to 14. display normal contact stress distribution across ring’s surface obtained from Simufact.forming simulation. Ring has been upset with nonimplanted dies.

Figures 15. to 17. display normal contact stress distribution across ring’s surface obtained from Simufact.forming simulation. Ring has been upset with implanted dies.

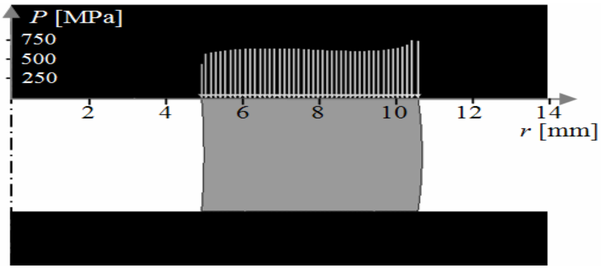


Figure 12. Normal contact stress distribution, die stroke 1.72 mm

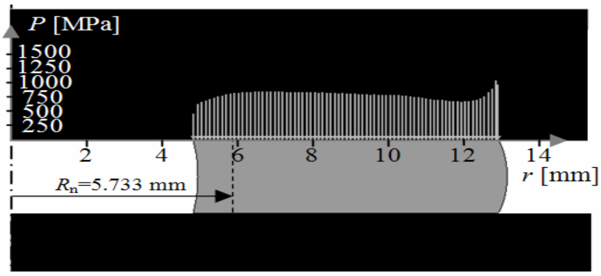


Figure 13. Normal contact stress distribution, die stroke 3.4 mm

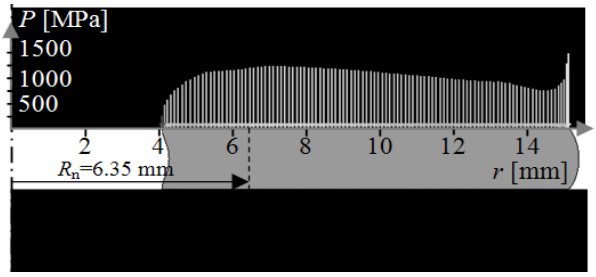


Figure 14. Normal contact stress distribution, die stroke 4.2 mm

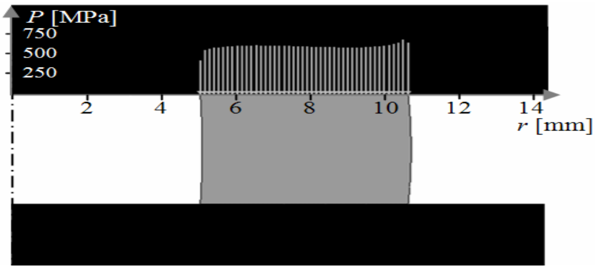


Figure 15. Normal contact stress distribution, die stroke 1.72 mm

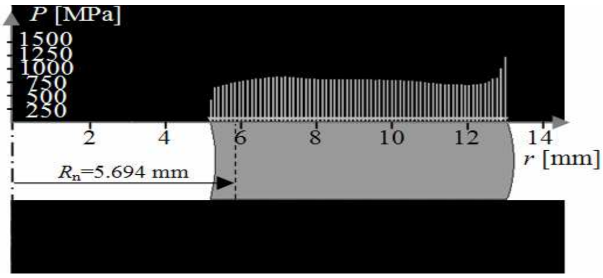


Figure 16. Normal contact stress distribution, die stroke 3.4 mm

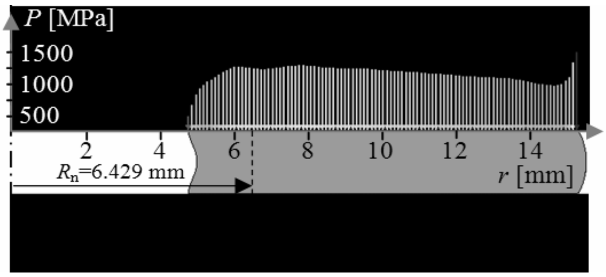


Figure 17. Normal contact stress distribution, die stroke 4.2 mm

5.4 Metallographic analysis

In order to evaluate results of neutral radius determination by numeric simulation, metallographic analysis was used.

Figures 18. and 19. present metallographic image of the ring upset with nonimplanted and implanted dies respectively and calculated neutral radius.

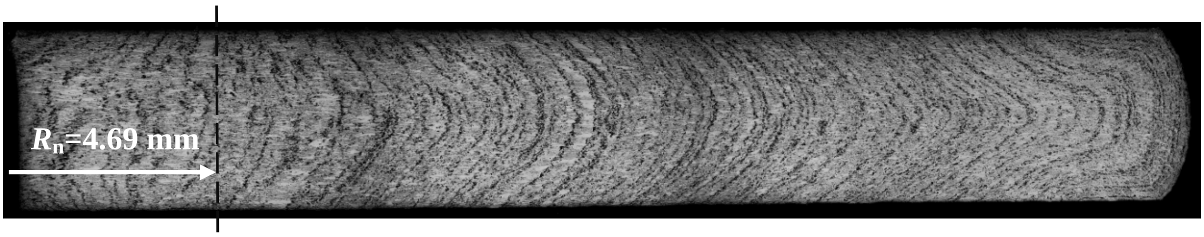


Figure 18. Metallography of the ring upset with nonimplanted dies (R_n=4.69 mm, D_1=5.1, D_2=28.75)

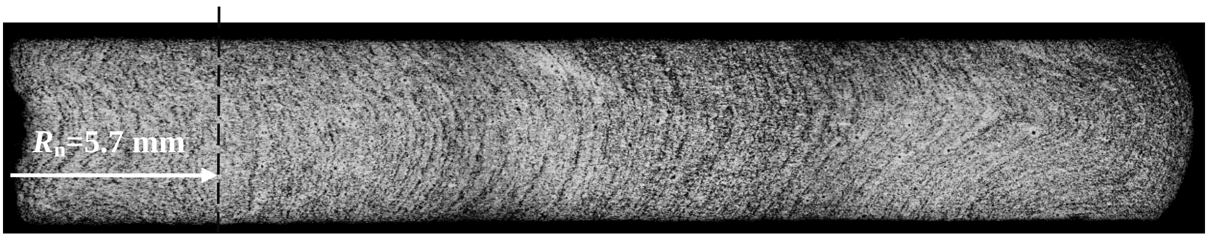


Figure 19. Metallography of the ring upset with implanted dies (R_n=5.7 mm, D_1=7.2, D_2=29.7)

6. DISCUSSION

It is evident from diagram (figure 5.) that ion implantation has influence on friction coefficient and therefore friction influences deformation of the ring's inner diameter.

Small differences in neutral radius values determined by numerical simulation and metallographic analysis can be explained with simulation's inability to take into account the real deformation conditions of material.

Neutral radius position at each upsetting phase in numerical simulation is determined from the distribution of tangential and normal contact stresses (figures 6. to 17.).

The magnitude of neutral radius depends on the friction coefficient. Based on figures 14, 17, 18 and 19 it can be concluded that at lower friction coefficient values neutral radius value is higher than at higher friction coefficient values. Also, by increasing die stroke the neutral radius is increased.

7. CONCLUSION

Based on the results presented in this paper, it can be concluded that ion implantation can reduce the friction coefficient and thus improve the process of material flow and filling of complex cavities at bulk forming process. Moreover, Simufact.forming simulation can be used for neutral radius determination since it provides approximately accurate values of neutral radius.

More comprehensive determination of the neutral radius at ring upsetting requires detailed micro-structural analysis of the rings at each deformation phase.

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REFERENCES

[1] A. Behrens, H. Schafstall: *2D and 3D simulation of complex multistage forging processes by use of adaptive friction coefficient*, Journal of Materials Processing Technology, 80-81, pp. 298-303, 1998.

[2] J. Schey: *Metal Deformation Processes*: Friction and Lubrication, Marcel Dekker Inc, New York, 1972.

[3] K. Lange: *Handbook of Metal Forming*, McGraw-Hill, Inc, 1985.

[4] M. Plančak, D. Vilotić: *Tehnologija plastičnog deformisanja*, Fakutlet tehničkih nauka, Univerzitet u Novom Sadu, Novi Sad, 2003.

[5] V. Vujović: *Obrada deformisanjem u mašinstvu 1. Deo*, Fakultet tehničkih nauka, Novi Sad, 1977.