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RESEARCH OF CORELATION BETWEEN FRICTION COEFFICIENT AND NANOMORPHOLOGY OF ION IMPLANTED DIES FOR COLD FORMING PROCESS

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Abstract: *In this paper investigation of surface nanomorphology of the dies for cold forming process, prior and after application of high contact loads, are shown. During the cold forming process, workpiece material (steel) is flowing across the die's surface with different friction effects, which depend on the effects of nitrogen ion implantation. Atomic force microscopy and scanning electron microscopy have been used for nanomorphology characterization of tribology pair surface. Significant decrease of surface roughness is characteristic for workpiece surface upset with ion implanted dies.*

Keywords: *friction coefficient, nanomorphology, ion implantation, cold forming process.*

1. INTRODUCTION

Our previous studies apparently prove that there is significant difference in a friction coefficient, between workpiece and die, depending if the surface of the die has been nanomodificated with ion implantation method or not [1, 2]. This is in accordance with other authors who investigated influence of nanomodification by ion implantation [3, 4].

As universal method for friction coefficient measurement in bulk metal forming processes, ring upsetting by flat plates (dies) is used [5, 6, 7].

Tool lifetime is directly dependant on surface phenomena that occur during exploitation, but most of all, adhesive and abrasive wear. Typical trend of tool's dimension change is characterized by first stage of adjustment, where surface roughness has a great influence on the wear phenomena [8]. Nowadays, when nano-precision machining is becoming more and more important area of mechanical engineering development, the tool surface must be modified in a way to lower roughness to nano scale values [9]. The second wear stage is characterized by the almost horizontal line of the tool dimension change that can be achieved only by improvement of mechanical properties of the surface layer. In the case of ultra precision machining, it means that during the second period of wear, tool dimensions can be changed only by few tenths of a nanometer, before the third wear period with a disastrous increase of wear rate begin. Therefore, in our work, we applied nanomodification on the surface of die in order to improve roughness and mechanical characteristics of the die's surface with depths around 30 to 100 nm.

This paper is a part of our research, that is related to SEM and AFM study of surface morphology transformation on the nanomodified die and workpiece, proving that ion implantation is promising technology for friction coefficient and wear rate reduction.

2. METHODS AND MATERIAL

Friction coefficient in bulk metal forming process is determined by calibration diagram wherein dependence of ring inner diameter deformation (ε_{Di}) on workpiece height deformation (ε_h) is drawn. Ring with D_o:D_i:h=6:3:2 dimensions ratio is used for experiment (figure 1).

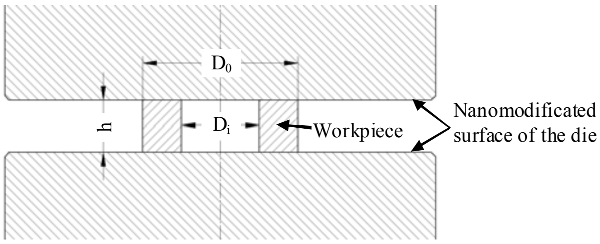

Figure 1. Ring upsetting process

Therefore, experiment plan was to investigate friction coefficient by ring upsetting by flat plates in two variants:

- hardened die (cold working steel, heat treated at 60 HRC), grinded and polished (figure 2, left die)
- hardened die (cold working steel, heat treated at 60 HRC), grinded, polished and implanted with dose $2 \cdot 10^{17}$ N^+ (figure 2, right die)

After ion implantation, dies implanted with $2 \cdot 10^{17}$ N^+ had visible colour change of nanomodificated surface to dark brown (figure 2).

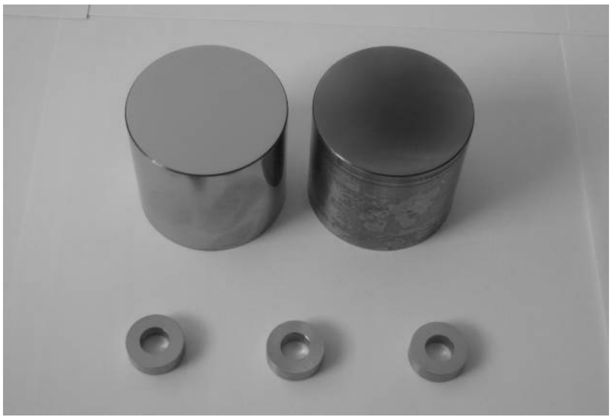

Figure 2. Implanted and nonimplanted die next to rings

Relatively simple ring shape has asymmetric material flow during upsetting process. Software Simufact.forming has been used for material flow phenomena analysis. Two distinctive zones (A and B) of material flow inside the rings has been noticed after upsetting (figure 3 and 12). Zone A has almost zero value of horizontal material flow. Contrary, B zone is distinguished by maximal value of horizontal flow over the tool surface.

Initial die and workpiece surface nanoroughness have been scanned by Veeco di CP-II AFM device with multiple inspections in order to insure statistical reliability of measurements. After upsetting process final result of surface morphology change is measured on the distinctive areas on the die and workpiece (zones A and B).

Die's and workpiece's morphology transformation is furthermore examined by SEM in order to merge SEM and AFM measuring results, which enabled getting better into the development of tribological phenomena at worn surfaces.

3. RESULTS

Material flow simulation by Simufact.forming software is presented on figure 3.

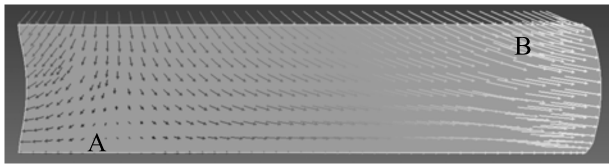

Figure 3. Simufact.forming results of ring upsetting with implanted dies

Typical SEM image of workpiece surface after upsetting process with implanted dies is presented on figure 4.

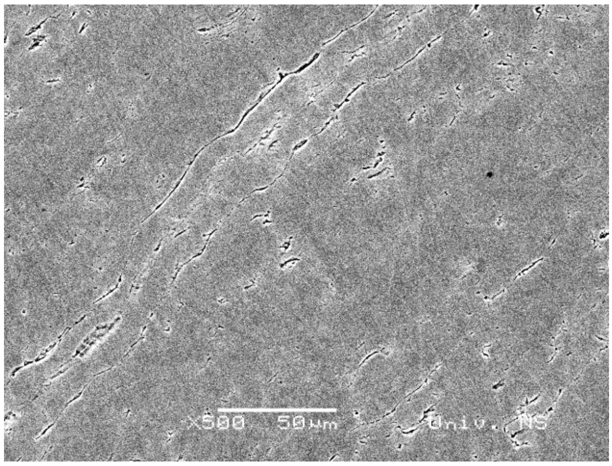

Figure 4. SEM image of zone A on ring upset with implanted dies

Corresponding AFM image of the same zone is given on figure 5.

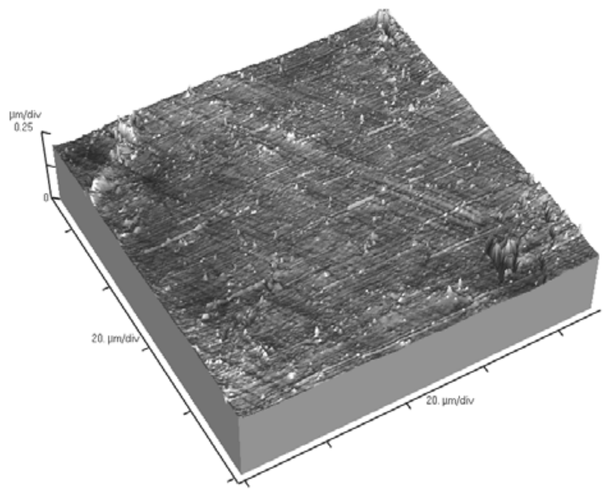

Figure 5. AFM image of zone A on ring upset with implanted dies

SEM and AFM images of B zone for the ring upset with implanted dies are on figure 6 and 7. Table 1 contains roughness parameters for the ring surface upset with implanted dies

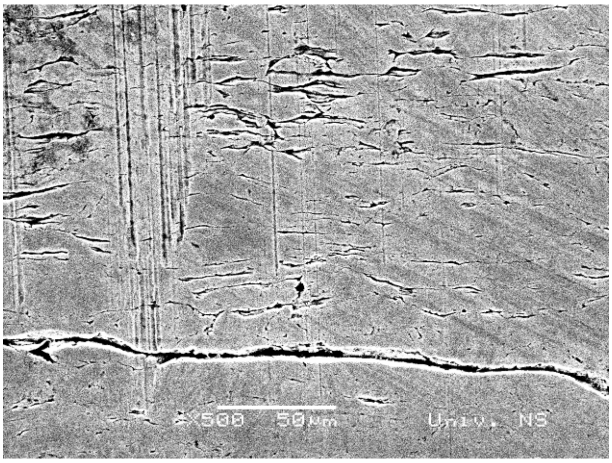

Figure 6. SEM image of zone B on ring upset with implanted dies

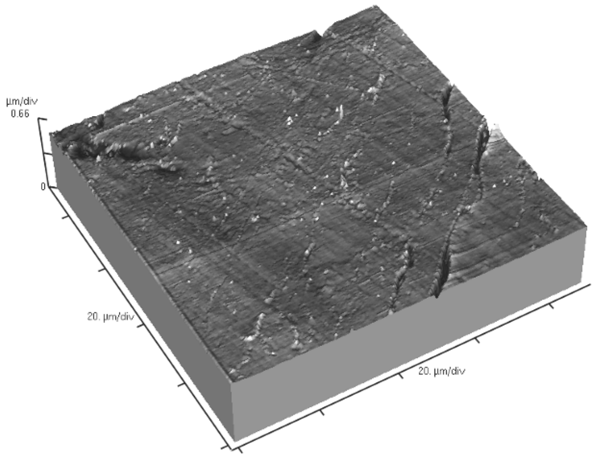

Figure 7. AFM image of zone B on ring upset with implanted dies

Table 1. Roughness parameters for ring upset with implanted dies

	Rp-v [nm]	Rms [nm]	Ra [nm]
zone A	508.1	17.54	9.875
zone B	1313	31.89	15.46
initial condition	2412.8±400	250.5±80	181.8±70

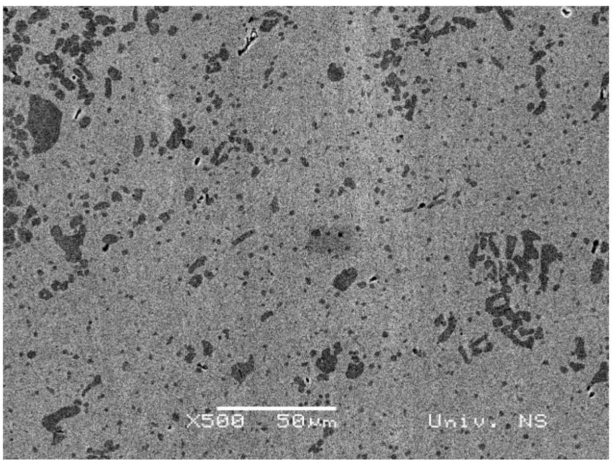

Figure 8. SEM image of zone A on ion implanted die

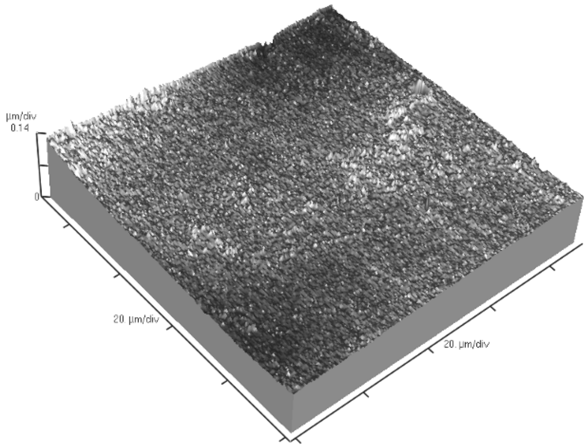

Figure 9. AFM image of zone A on ion implanted die

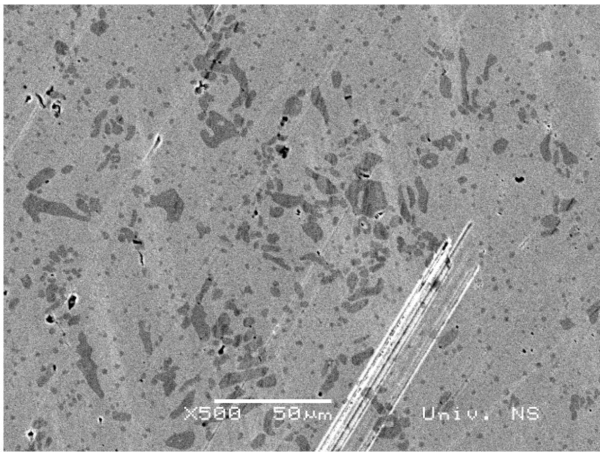

Figure 10. SEM image of zone B on ion implanted die

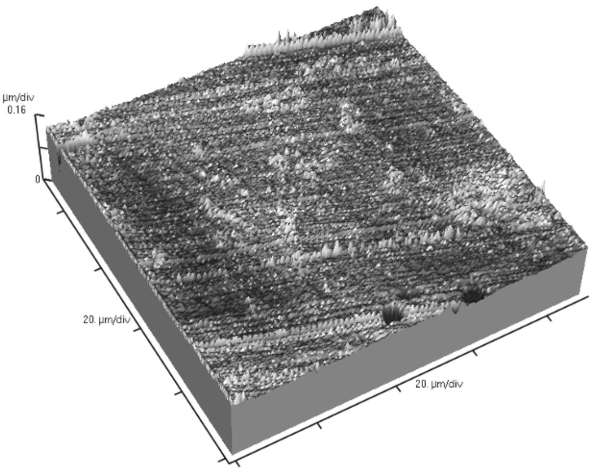

Figure 11. AFM image of zone B on ion implanted die

Table 2. Roughness parameters for implanted die after upsetting process

	Rp-v [nm]	Rms [nm]	Ra [nm]
zone A	202.9	7.167	5.316
zone B	307.1	9.990	6.179
initial condition	291.3±200	13.0±6	7.9±2

Nanomorphology change of the die's surface is significantly lower in the case of upsetting with ion implanted dies, which can be clearly noticed from tables 2 and 4. After upsetting process, initial R_a values on ion implanted dies, drops from 7.9±2 nm to 5.316 nm in zone A and 6.179 nm in zone B. This can be confirmed by AFM and SEM images (figures 8, 9, 10 and 11). In the case of nonimplanted dies initial R_a values rises from 12.0±3 nm to 13.78 nm in zone A and to 29.19 nm in zone B after upsetting proces.

In the case of ring upset with implanted and nonimplanted dies, higher roughness decrease can be seen in the case of ring upset with ion implanted dies (tables 1 and 3). Initial R_a value drops from 181.8±70 nm to 9.875 nm in zone A and to 15.46 nm in zone B. Difference in R_a values between ring upset with implanted dies and ring upset with nonimplanted dies is 1.9 times in zone A and 3.61 times in zone B.

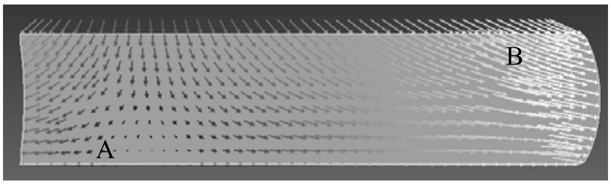

Figure 12. Simufact.forming results of ring upsetting with nonimplanted dies

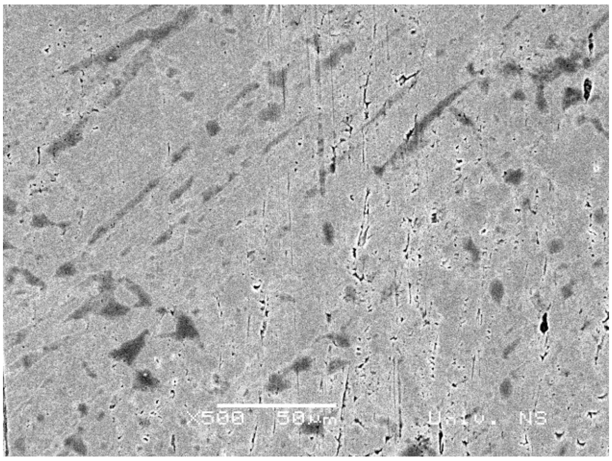

Figure 13. SEM image of zone A on ring upset with nonimplanted dies

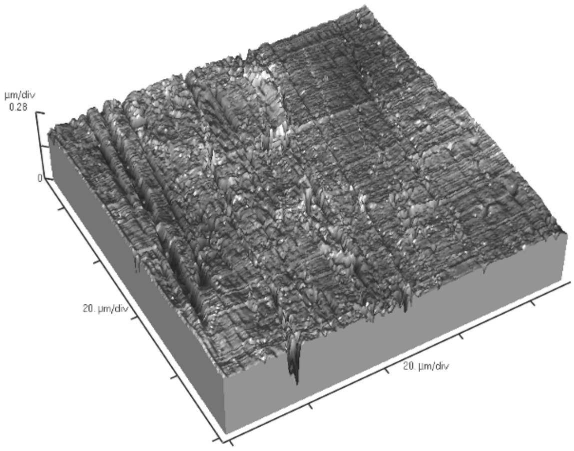

Figure 14. AFM image of zone A on ring upset with nonimplanted dies

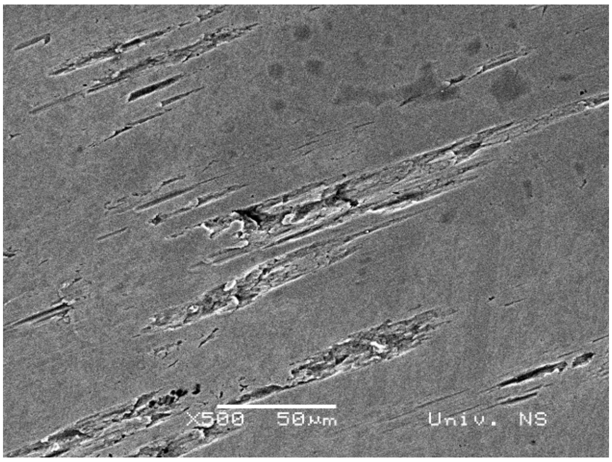

Figure 15. SEM image of zone B on ring upset with nonimplanted dies

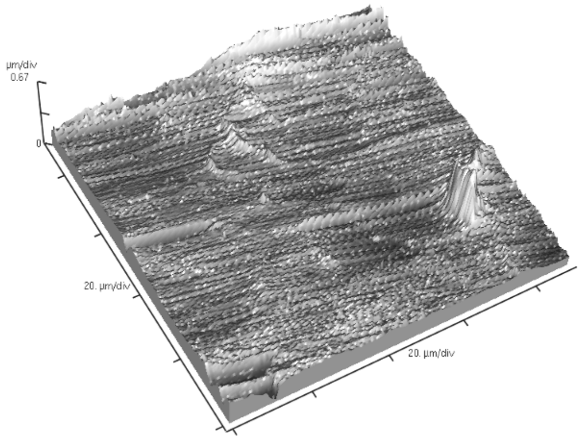

Figure 16. AFM image of zone B on ring upset with nonimplanted dies

Table 3. Roughness parameters for ring upset with nonimplanted dies

	Rp-v [nm]	Rms [nm]	Ra [nm]
zone A	557.2	30.44	18.77
zone B	1343	87.12	55.84
initial condition	2596.3±800	256.8±80	196.9±50

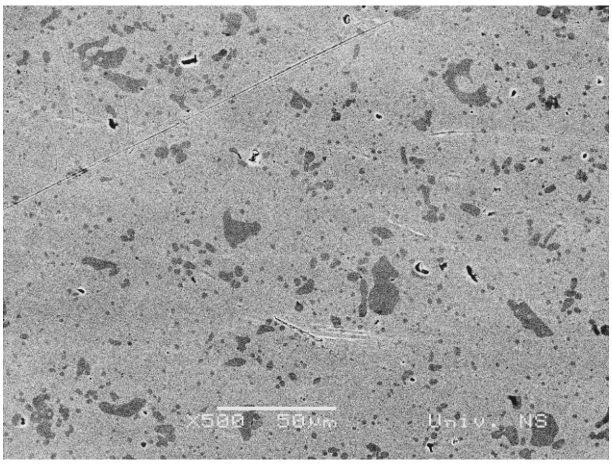

Figure 17. SEM image of zone A on nonimplanted die

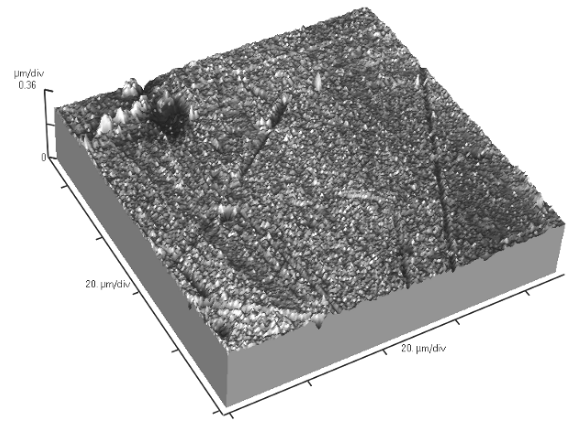

Figure 18. AFM image of zone A on nonimplanted die

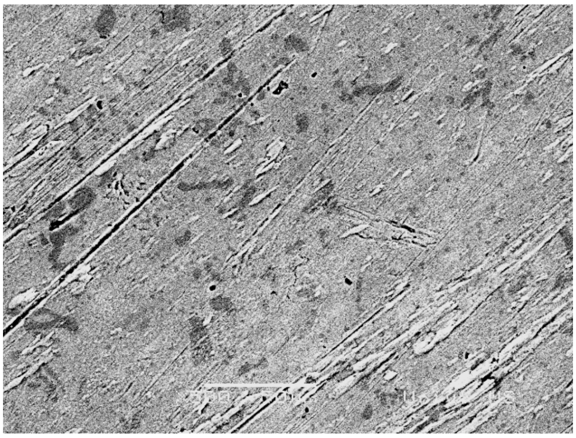

Figure 19. SEM image of zone B on nonimplanted die

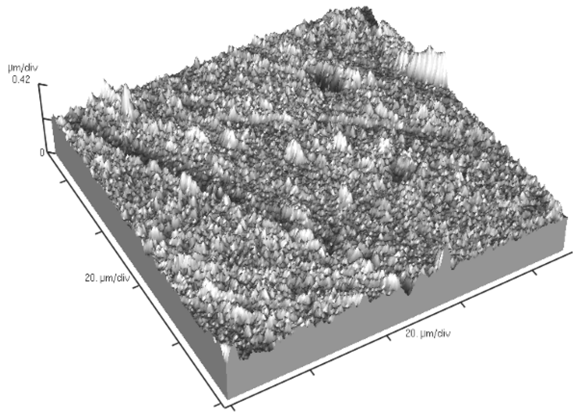

Figure 20. AFM image of zone B on nonimplanted die

Table 4. Roughness parameters for nonimplanted die after upsetting process

	Rp-v [nm]	Rms [nm]	Ra [nm]
zone A	725.2	21.62	13.78
zone B	831.0	42.01	29.19
initial condition	514.8±200	19.3±6	12.0±3

Final results of experiment, i.e. friction factors (m) for different conditions, are presented in figure 21 in a form of chart, where influence of ion modification on friction parameters, during upsetting process, can be clearly seen. It is clear visible that ion implantation significantly lowers friction coefficient, whic can be explained by nanomorphology phenomena on different treated die.

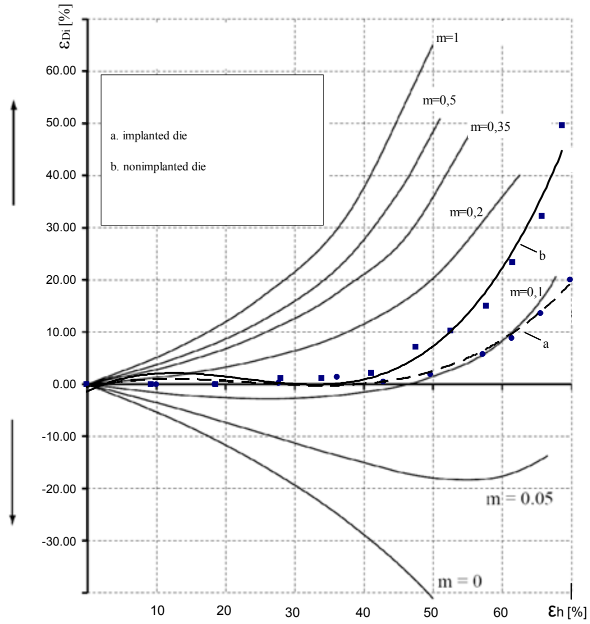

Figure 21. Experimental results of friction factor for rings upset with implanted and nonimplanted dies

Summary results of friction coefficient examination are in the table 5.

Table 5. Summary results of friction factor and friction coefficient

Die	m	μ
Hardened	0.15	0.087
Hardened+implanted	0.1	0.058

4. CONCLUSION

Roughness of the workpiece can be reduced with upsetting by proper dies i.e. more precise workpiece can be obtained by using ion implanted dies.

After implantation and ring upsetting process lower surface roughness on the implanted die can be easily noticed. Due to upsetting and material flow across the surface of the die, die's roughness is changing differently in zone A and zone B. Surface quality for implanted die is much higher, which then explains lower friction coefficient during ring upsetting process.

In industrial application of dies for cold forming process, desired quality of produced workpiece is very important. With implanted dies, R_a can be reduced almost 20 times, whereby roughness in zone A is visibly lower than roughness in zone B on upset ring. Similar tendency is present with nonimplanted dies, but the workpiece's roughness is three times greater than in the case of upsetting with implanted dies.

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