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DIE SURFACE NANOMODIFICATION IN BULK COLD FORMING

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ABSTRACT:
In this paper several results of research of nitrogen ion implantation into the surface of the die for bulk cold forming are presented. The aim of these researches was to examine the influence of die's surface nanomodification on friction phenomena and workpiece morphology change. Ring test was used as standard method for friction coefficient determination in cold bulk forming technology. Workpiece surface morphology was monitored by atomic force microscope. During the analysis there was a comparison of the process where lubrication was and was not applied between die's and workpiece's surface. Obtained results clearly show that with nanomodification can substantially influence friction coefficient and workpiece surface morphology, or in other words, it can significantly influence the quality of cold formed parts.

KEYWORDS:
friction, ring test, ion implantation, nanomodification

1. INTRODUCTIONS

Contemporary industry is more and more stepping toward ultra precise machining, where dimensions of workpieces and dies are defined in nanometers [11]. The quality of the workpiece machined surface is especially important, since more and more constructions demands nano precise components. Bulk cold forming is suitable for serial and mass production where die's durability and precision is demanded. Parameters of friction are very important for cold forming process since they affect the operation of the die and workpiece surface quality [9, 1].

Based on our previous researches [2, 3] it is concluded that most suitable method is nanomodification by nitrogen ion implantation [6, 8]. In this case we opted for an implantation of single charged ions with high density beam. Depending of the applied dose, this method can provide the reduction of roughness and an increase of nanohardness in the surface layer with a depth up to 30 nanometers. [4]. Therefore, an effect of friction coefficient reduction and an increase of tool life, during bulk cold forming, should appear on the surface of nanomodificated die.

In metal forming technology various methods for friction coefficient measurement are used [10, 5, 7]. Methods are arranged in accordance to individual technology, because it is considered that friction coefficient measurement in actual circumstance should be associated with technology for which friction coefficient will be measured.

As universal method for friction coefficient measurement in bulk metal forming processes, ring upsetting by flat plates is used. Method is simple and it provides satisfactory results. Friction coefficient is determined by calibration diagram wherein dependence of ring inner diameter deformation (ε_{Di}) on workpiece height deformation (ε_h) is drawn. Ring with

Do:Di:h=6:3:2 dimensions ratio is used for experiment (figure 1). This method was used for friction coefficient measurement in this paper.

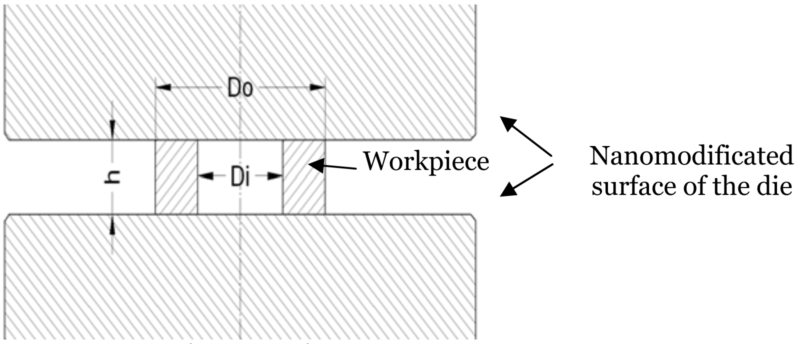


Figure 1. Ring upsetting process

2. METHODOLOGY

Objective of experimental investigation was to determine the influence of surface type and surface finish on contact friction coefficient. 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 (see figure 2, left die)
- hardened die (cold working steel, heat treated at 60 HRC), grinded, polished and implanted with $2x10^{17}$ N^+, 50keV dose (see figure 2, right die)

Figure 2. Implanted and nonimplanted die next to rings

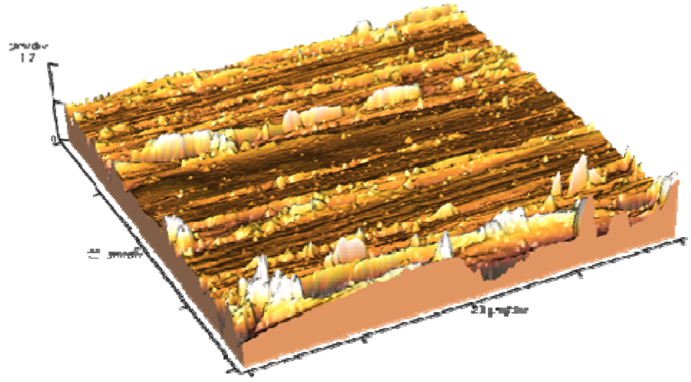
As it can be seen from the figure 2, dies implanted with $2x10^{17}$ N^+, 50keV dose had visible color change to dark brown. Also, initial dimensions of the workpieces can bee seen in figure 2. Every surface of the workpiece was multiple checked, for sake of assurance. Initial state of nanoroughness was measured by AFM of both sample's surface.

During experiment, rings with initial dimensions Do:Di:h=18:12:6 mm were used (see figure 7). Conditions on contact surface were also defined in two variants:

- lubrication with oil for cold metal forging
- without lubrication

3. FINAL RESULTS

Example of initial roughness of the rings before upsetting (which were grinded and polished) was determined by AFM microscope (see figure 3 and 4). After upsetting process, there was a dramatic change in ring's roughness magnitude (see figure 5 and 6).



	Rp-v	Rms Rough (Rq)	Ave Rough (Ra)	Mean Ht	Median Ht	Peak (Rp)	Valley (Rv)	Volume	Surface Area	Projected Area
Region 1	7.720 µm	225.0 nm	107.7 nm	6.409 µm	6.408 µm	1.311 µm	-6.409 µm	4.102e+004 µm³	7198. µm²	6400. µm²

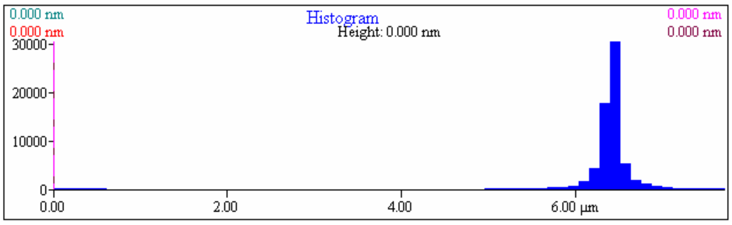
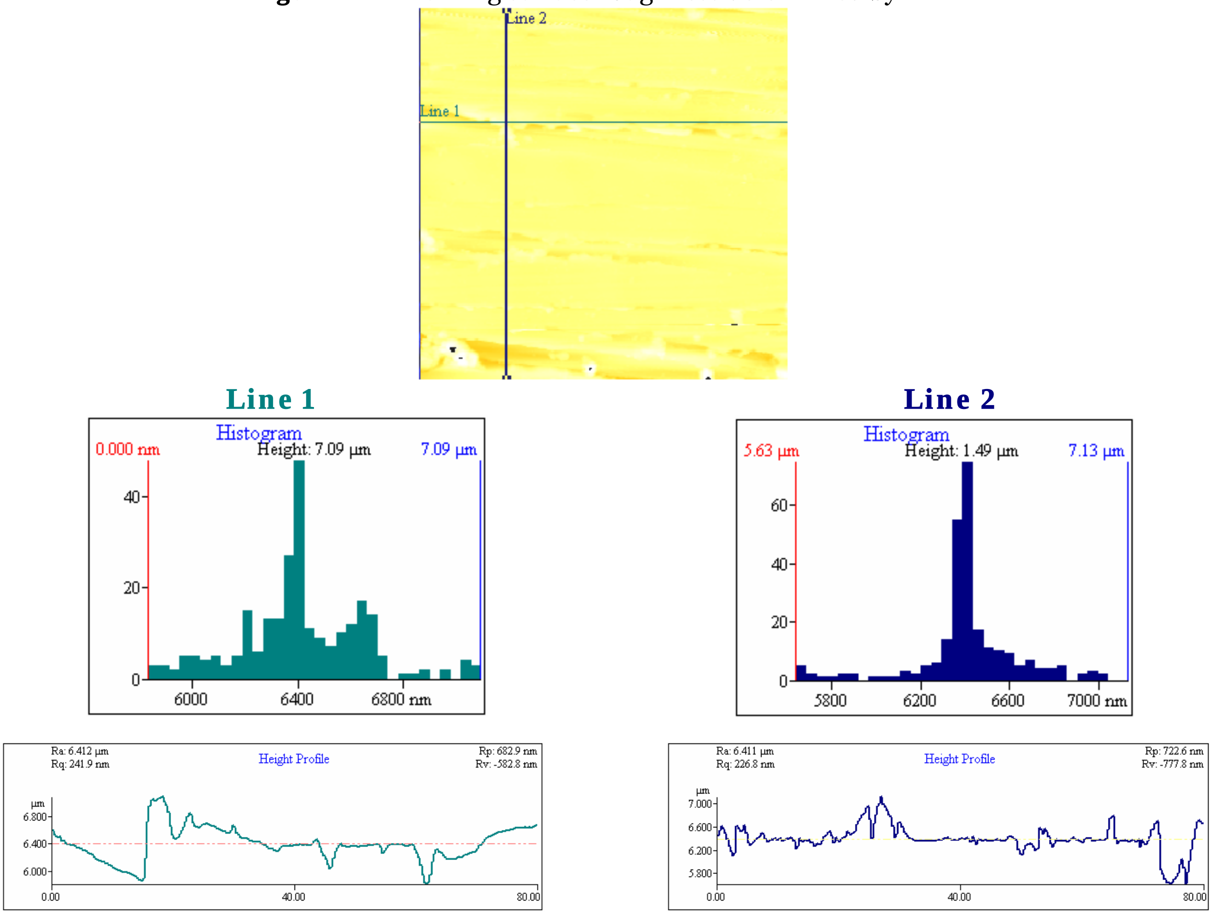
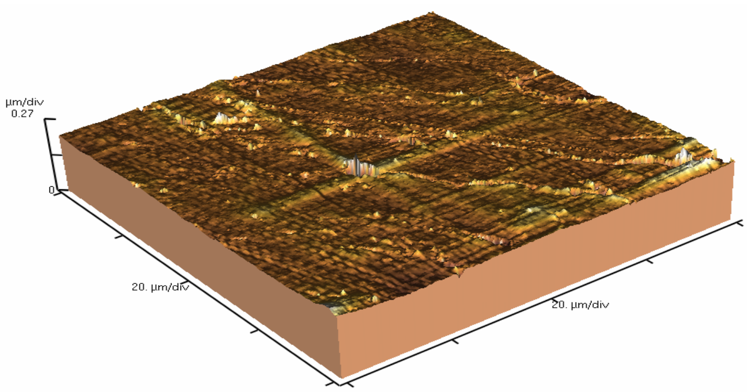


Figure 3. Initial ring surface roughness determined by AFM



	Rp-v	Rms Rough (Rq)	Ave Rough (Ra)	Mean Ht	Median Ht	Peak (Rp)	Valley (Rv)
Line 1	1.266 µm	241.9 nm	177.7 nm	6.412 µm	6.395 µm	682.9 nm	-582.8 nm
Line 2	**1.500 µm**	**226.8 nm**	**134.9 nm**	**6.411 µm**	**6.396 µm**	**722.6 nm**	**-777.8 nm**

Figure 4. Initial ring line 1 and 2 roughness determined by AFM



	Rp-v	Rms Rough (Rq)	Ave Rough (Ra)	Mean Ht	Median Ht	Peak (Rp)	Valley (Rv)	Volume	Surface Area	Projected Area
Region 1	544.1 nm	15.89 nm	6.861 nm	425.5 nm	425.8 nm	118.6 nm	-425.5 nm	2723. µm³	6404. µm²	6400. µm²

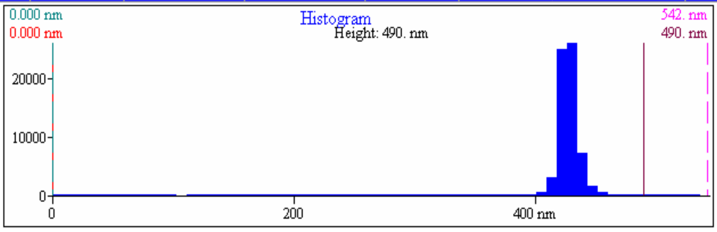
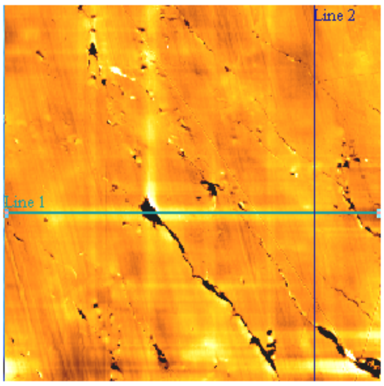
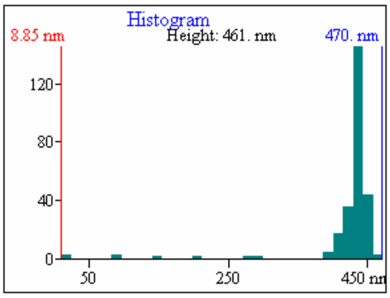


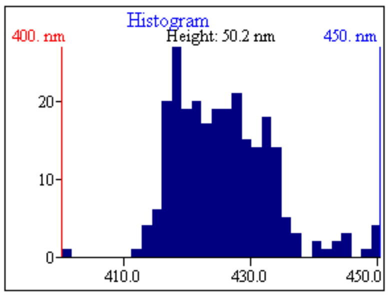
Figure 5. Roughness of the ring surface after upsetting process with implanted dies, without oil lubrication, determined by AFM

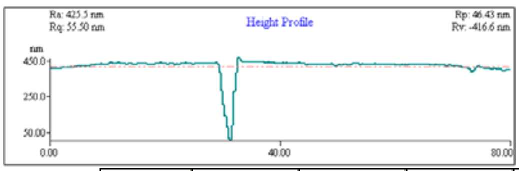


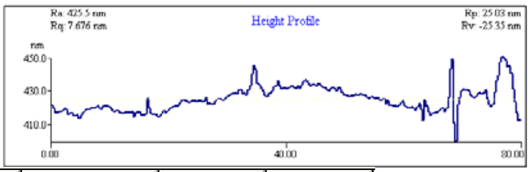
Line 1



Line 2





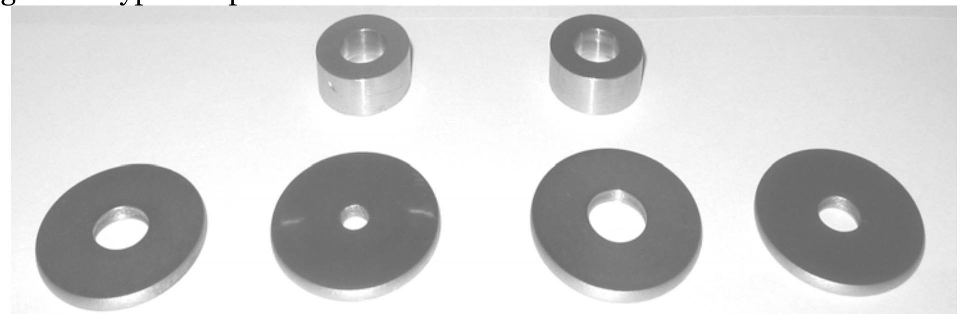


	Rp-v	Rms Rough (Rq)	Ave Rough (Ra)	Mean Ht	Median Ht	Peak (Rp)	Valley (Rv)
Line 1	**463.1 nm**	**55.50 nm**	**22.12 nm**	**425.5 nm**	**437.6 nm**	**46.43 nm**	**-416.6 nm**
Line 2	50.38 nm	7.676 nm	6.060 nm	425.5 nm	425.0 nm	25.03 nm	-25.35 nm

Figure 6. Roughness of the ring in lines 1 and 2 after upsetting process with implanted dies, without oil lubrication, determined by AFM

Determination of $\varepsilon_{Di} = f(\varepsilon_h)$ functionality was conducted by successive ring upsetting, with nominal height deformation of $\Delta\varepsilon_h = 0{,}1$.

Results of ring geometry measurement and calculation of strains are given in the following tables (see tables 1, 2, 3 and 4). Typical appearance of the rings after experiment is presented in figure 7. It is obvious even visually, that there is different effect of upsetting depending on die type and presence of lubrication.



a) b) c) d)

Figure 7. Representative rings before and after upsetting
a) Ring upset with nonimplanted dies with oil lubrication; b) Ring upset with nonimplanted dies without oil lubrication; c) Ring upset with implanted dies with oil lubrication; d) Ring upset with implanted dies without oil lubrication

Table 1. Experimental data for ring upset with nonimplanted dies with oil lubrication

Measurement no.	Height h [mm]			Diameter Di [mm]			Diameter Do [mm]			Load	ε_{Di}	ε_h
	h'	h''	$h_{average}$	D'_i	D''_i	$D_{i\ average}$	D'_o	D''_o	$D_{o\ average}$	kN		
0	5.85	5.85	5.85	8.95	8.95	8.95	18.1	18.1	18.1	0	0.00	0.00
1	5.3	5.3	5.3	9	9	9	18.8	18.8	18.8	80	-0.56	9.40
2	4.85	4.9	4.875	9.05	9.15	9.1	19.55	19.5	19.5	125	-1.68	16.67
3	4.4	4.4	4.4	9.3	9.2	9.25	20.35	20.4	20.375	150	-3.35	24.79
4	4	4	4	9.3	9.3	9.3	21.15	21.2	21.15	175	-3.91	31.62
5	3.7	3.7	3.7	9.55	9.6	9.575	22.1	22	22.025	200	-6.98	36.75
6	3.3	3.3	3.3	9.25	9.75	9.5	23.8	22.9	23.35	230	-6.15	43.59
7	3.05	3.05	3.05	9.85	9.2	9.525	23.55	24.4	23.95	260	-6.42	47.86
8	2.7	2.7	2.7	9.85	9.1	9.475	24.4	25.2	24.8	300	-5.87	53.85
9	2.45	2.45	2.45	9.75	9.2	9.475	26.2	25.6	25.9	350	-5.87	58.12
10	2.25	2.25	2.25	9.4	9	9.2	27.3	27.1	27.175	410	-2.79	61.54
11	2.05	2.05	2.05	9.2	8.8	9	28.7	28.2	28.45	480	-0.56	64.96

Table 2. Experimental data for ring upset with nonimplanted dies without oil lubrication

Measurement no.	Height h [mm]			Diameter Di [mm]			Diameter Do [mm]			Load	ε_{Di}	ε_h
	h'	h''	$h_{average}$	D'_i	D''_i	$D_{i\ average}$	D'_o	D''_o	$D_{o\ average}$	kN		
0	5.9	5.9	5.9	9	9	9	18	18	18	0	0.00	0.00
1	5.35	5.35	5.35	9	9	9	18.75	18.8	18.75	100	0.00	9.32
2	4.8	4.8	4.8	9	9	9	19.65	19.7	19.675	140	0.00	18.64
3	4.25	4.25	4.25	8.9	8.9	8.9	20.55	20.6	20.575	160	1.11	27.97
4	3.9	3.9	3.9	8.9	8.9	8.9	21.35	21.5	21.4	195	1.11	33.90
5	3.5	3.45	3.475	8.85	8.75	8.8	22.5	22.4	22.45	240	2.22	41.10
6	3.1	3.1	3.1	8.4	8.3	8.35	23.35	23.4	23.35	280	7.22	47.46
7	2.8	2.8	2.8	8	8.15	8.075	23.4	23.3	23.35	340	10.28	52.54
8	2.5	2.5	2.5	7.8	7.5	7.65	25.4	25.4	25.375	430	15.00	57.63
9	2.3	2.25	2.275	6.8	7	6.9	26.6	26.4	26.5	525	23.33	61.44
10	2	2.05	2.025	6.1	6.1	6.1	27.75	27.7	27.7	670	32.22	65.68
11	1.85	1.85	1.85	4.4	4.7	4.55	28.7	28.8	28.75	915	49.44	68.64

Table 3. Experimental data for ring upset with implanted dies with oil lubrication

Measurement no.	Height h [mm]			Diameter Di [mm]			Diameter Do [mm]			Load	ε_{Di}	ε_h
	h'	h"	$h_{average}$	D'$_i$	D"$_i$	$D_{i\ average}$	D'$_o$	D"$_o$	$D_{o\ average}$	kN		
0	5.95	5.95	5.95	9	9	9	18	18	18	0	0.00	0.00
1	5.4	5.4	5.4	9.15	9.1	9.125	18.65	18.8	18.7	100	-1.39	9.24
2	5.05	5.05	5.05	9.4	9.4	9.4	19.3	19.2	19.25	120	-4.44	15.13
3	4.65	4.7	4.675	9.5	9.5	9.5	19.9	20	19.95	140	-5.56	21.43
4	4.2	4.2	4.2	9.85	9.85	9.85	21	21.1	21.05	170	-9.44	29.41
5	3.85	3.85	3.85	10	10.05	10.025	22	22	22	195	-11.39	35.29
6	3.35	3.4	3.375	10.2	10.35	10.275	23	22.9	22.95	235	-14.17	43.28
7	3.05	3.1	3.075	10.2	10.5	10.35	23.6	24	23.8	255	-15.00	48.32
8	2.8	2.8	2.8	10.45	10.6	10.525	25	25.1	25.05	300	-16.94	52.94
9	2.55	2.55	2.55	10.55	10.6	10.575	26.3	26.1	26.2	340	-17.50	57.14
10	2.2	2.2	2.2	10.6	10.3	10.45	27.5	28	27.75	430	-16.11	63.03
11	1.85	1.9	1.875	10.7	10	10.35	29.3	30	29.65	540	-15.00	68.49

Table 4. Experimental data for ring upset with implanted dies without oil lubrication

Measurement no.	Height h [mm]			Diameter Di [mm]			Diameter Do [mm]			Load	ε_{Di}	ε_h
	h'	h"	$h_{average}$	D'$_i$	D"$_i$	$D_{i\ average}$	D'$_o$	D"$_o$	$D_{o\ average}$	kN		
0	5,95	5,95	5,95	9	9	9	18	18	18	0	0,00	0,00
1	5,35	5,35	5,35	9	9	9	18,8	18,8	18,8	110	0,00	10,08
2	4,85	4,85	4,85	9	9	9	19,6	19,7	19,65	140	0,00	18,49
3	4,3	4,3	4,3	8,95	9	8,975	20,5	20,4	20,45	170	0,28	27,73
4	3,8	3,8	3,8	8,8	8,95	8,875	21,4	21,5	21,45	200	1,39	36,13
5	3,4	3,4	3,4	8,9	9	8,95	22,6	22,5	22,55	230	0,56	42,86
6	3	3	3	8,95	8,7	8,825	23,7	23,6	23,65	280	1,94	49,58
7	2,55	2,55	2,55	8,3	8,65	8,475	25,1	25,2	25,15	350	5,83	57,14
8	2,3	2,3	2,3	8,1	8,3	8,2	26,5	26,5	26,5	420	8,89	61,34
9	2	2,1	2,05	7,95	7,6	7,775	27,8	28	27,9	520	13,61	65,55
10	1,8	1,8	1,8	7	7,4	7,2	29,7	29,7	29,7	645	20,00	69,75

Final results of experiment, i.e. friction factors (m) for different conditions, are presented in figure 8. Final result of the experiment is provided in a form of chart, where influence of lubrication and ion modification of dies on friction parameters, during upsetting process, can be clearly seen.

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

Table 5. Summary results of friction factor and friction coefficient

Die	Lubricated		Without lubrication	
Hardened	m=0,075	μ=0,043	m=0,15	μ=0,087
Hardened+implanted	m=0,05	μ=0,029	m=0,1	μ=0,058

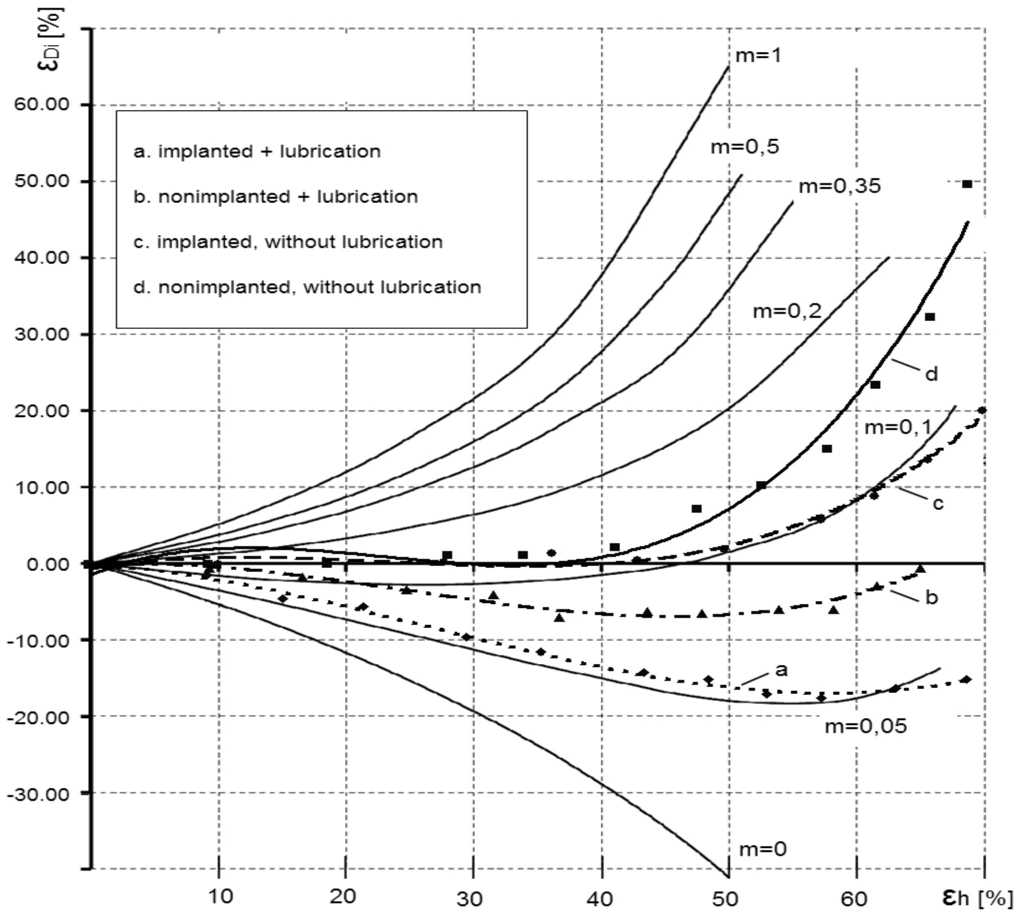


Figure 8. Experimental results of friction factor for different conditions.

4. CONCLUSIONS

Friction coefficient reduction in metal forming technologies is of great importance for forming process, since contact stresses, forming load and deformation work are decreasing in this manner. Reduction of friction coefficient also reduces die wear and prolongs die lifetime.

Result of friction coefficient measurement shows that apart from method of lubrication, treatment of die's contact surface has great effect on friction coefficient magnitude. Magnitudes of all measured friction coefficients are relatively low, but there is clear difference between them. Ratio of friction factor in case of nonimplanted die and implanted die is 0,075/0,05=1,5 when oil as lubricant was used and 0,15/0,10=1,5 when lubrication was not used.

In case of same die type, lubrication also significantly affects the friction. Ratio of friction factor in case of no lubrication and in case of oil lubrication is 0,15/0,075=2 among nonimplanted dies and 0,10/0,05=2 among ion implanted dies.

Based on conducted experiments and results analysis, it is concluded that in process of bulk metal forming, ion implantation has very significant impact on friction reduction.

General conclusion of our research so far is that nanomodification of die's surface has significant effect on friction and wear phenomena among bulk metal forming process. Therefore, future researches are planned with different dosage and different ions, in order to discover optimal variant for tool improvement.

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