STUDY OF ALTERNATIVE LUBRICANTS TO THE COLD EXTRUSION OF STEEL SHAFTS

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Abstract. *Lubrication plays an important role in cold extrusion since efficient lubricants prevent direct metallic contact. Low friction coatings and oils are used to prevent seizure, reduce friction stresses, limit the wear and cool the tools. Nevertheless, they are not sufficient to ensure the lubrication of all regions of the forming billet. In industrial processes, lubrication is time consuming and presents significant environmental impacts related to the disposal and discard of the many materials used to prepare and to lubricate the billets. In most industrial processes, the zinc crystalline phosphatization associated with a soap or* MoS_2 *lubricant significantly improves the friction conditions at the interface and severe sequences of cold extrusion are possible. Mineral oils are a good alternative to substitute the lubricants commonly used in cold extrusion. Two mineral oils and one solid lubricant were analyzed with an experimental set up where the surface of the billet was properly modified in its texture to become an efficient lubricant carrier substituting the zinc phosphate coating. Results of the tests are shown for the extrusion loads and surface roughness. These results are compared to those obtained in same conditions with traditional lubricants, to define the best alternative lubricant and billet surface finishing.*

Keywords. *cold extrusion, lubricants, friction, phosphatization.*

1. Introduction

1.1 Lubrication in cold extrusion of steel parts

Lubrication plays an important role in cold extrusion since efficient lubricants prevent direct metallic contact, with the reduction of extrusion loads and wear, and the improvement of products quality and tools life. Low friction coatings and oils are used to prevent seizure, reduce friction stresses, limit the wear and to cool the tools. However, they are not sufficient to ensure the lubrication of all regions of the forming billet (Lazzarotto *et al*., 1998-a).

Cold extrusion of steel parts is becoming increasingly important to the manufacturing industries due to recent advances in tool and press design and in tool materials. The main advantages of this process are products with good dimensional accuracy and smooth surface finish, reduced stock material and post machining, and also improvements in mechanical properties (Jang *et al*., 2001).

However, this process requires high amount of mechanical energy to deform the workpiece. It means that high temperatures occur in the forming zone where workpiece and tool come into strong contact, which may impair or even completely nullify the effect of normal lubricants.

Many reactions at the interface tool-billet are influenced by the physical and chemical properties of the materials and affect significantly the wear and surface quality. In most processes, the zinc crystalline phosphatization associated to a soap or MoS_2 lubricant significantly improves the friction conditions at the interface and severe sequences of cold extrusion are possible (Donofrio, 2000).

The billet is coated by a phosphate (e.g. zinc phosphate) and a film is formed prior to the forming process. Despite being an effective lubricant carrier, this coating requires many complex and costly production steps, and its reproducibility is sometimes random (Komatsuzaki *et al.,* 1996, Dubar *et al.,* 1998). After the phosphate is formed, a soap (sodium or calcium stearate) or MoS_2, for larger area reductions, reacts with the phosphate to form a film of zinc stearate. The efficiency of this film depends on process variables like temperature, concentration, acidity and bath time (Lazzarotto *et al.*, 1999).

1.2. Environmental problems related to cold forming lubrication

The coating process presents significant environmental impacts related to the disposal and discard of the many materials used to prepare and to lubricate the billets (acid and alkaline baths, phosphates). The global drive towards the use of lubricants benign to health and environment demands substitutes for traditional lubricants, often flammable with active elements such as chlorine, sulfur, and phosphorous, which are potentially hazardous. Industrial sludges have shown a rapid increase in quantity and complexity of components (Levy, 2000), and the discard and destruction became an important environmental problem (Nyamangara, 1998).

This is specifically true for sludges from the coating of metallic parts that present a large variation of pH, phosphates, many toxic heavy metals, solvents and protective oils (Levy, 2000). The cost to discard these sludges can contribute significantly to the cost of the final products (Baldy, 1996).

Most of the solids found in these sludges are metallic compounds like hydroxides of copper, zinc, cadmium, nickel, iron, aluminum, chromium and calcium. They cannot be incinerated because many toxic metals like zinc, lead and cadmium can be volatized (Levy, 2000). Because they are not easily lixiviated, zinc and copper accumulate in the soils, leading to environmental concerns related to the large concentrations of these metals observed recently in many industrial areas (Nyamangara, 1998).

Therefore, it is necessary to define lubricants more suitable for metal forming process that do not present these environmental problems and do not increase products cost.

1.3 – Alternative lubricants

Mineral oils are a good alternative to substitute lubricants commonly used in cold extrusion, if the appropriate conditions are chosen to the process parameters, like lubricant viscosity, area reduction, speed and tool geometry. Komatsuzaki *et al.* (1996) showed that in forward extrusion, the anti-seizure property could be improved fairly simply when condensed phosphoric acids were directly added to lubricating oils together with monoalkyl phosphates or dialkyl phosphites. Lazzarotto *et al.* (1998-b) show a methodology to the selection of lubricant oils in cold metal forming processes, from a wide range of products available on the market, because the lubricant has an economic importance and its proper selection can save production costs.

Kudo (1965) showed that friction is affected by the amount of lubricant carried between the rough metallic surfaces in contact, indicating how the surface topography is important.

In the same work, it was showed that topographies with different groove angles do not affect the stress caused by friction. Tests were hold to define the quantity of lubricant retained in many texturized surfaces of rings under axial compression. Polished surfaces showed five times more retained lubricant than rougher surfaces. However, polished surfaces may not be practical in industries and more work is necessary to investigate other parameters that influence the deformed surface, and that could be optimized to minimize the friction when liquid lubricants are used (Hu and Dean, 2000).

Lazzarotto et al. (1998-a e 1998-b) showed some methods to choose lubricant oils based on direct extrusion tests to define the lubrication efficiency of several mineral oils with addictives for the extreme pressures present in cold extrusion.

2. Materials and methods

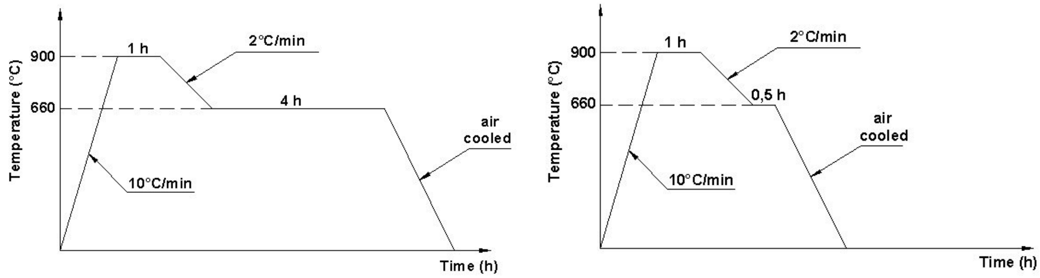
In this work, some methods of surface texturization were used to study the efficiency of the lubricants and to define how much lubricant was retained during cold extrusion of steel billets. These tests were hold in an experimental set up and it was analyzed the efficiency of some mineral oils and solid soaps.

2.1 Billets

AISI 8620 billets were cold extruded to evaluate the lubricants efficiency. This steel shows good hardenability when case carburized, quenched and tempered. Also, it shows a good workability when cold formed (Metals Handbook, 1990).

Billets were heat treated in two different conditions: annealed and normalized. The annealed condition is the best for cold forming due to the ferrite present in its microstructure. To reduce the costs involved in the process, there were also tests with normalized billets that represent the commercial condition.

Figure 1-a shows the conditions of heat treatment for spheroidizing annealing and Fig. 1-b shows the conditions for full annealing. The spheroidizing annealing was necessary because the billet hardness after full annealed was too high to allow extrusion tests with the liquid lubricants because the extrusion loads exceeded the load cell capacity.

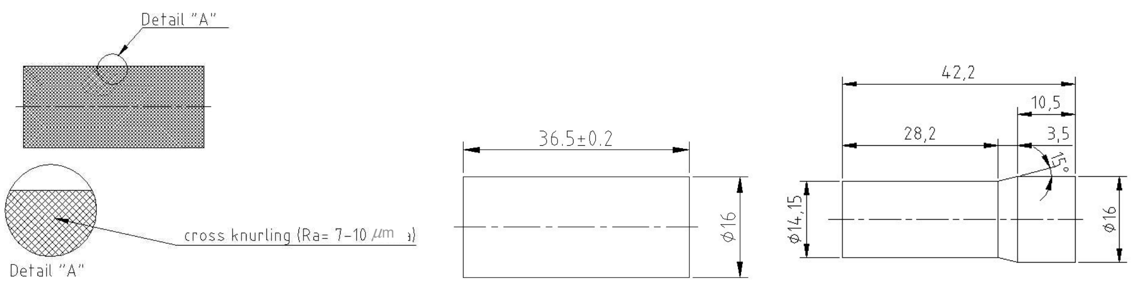


(a) (b)

Figure 1. Heat treatment conditions to billet annealing.

Two different surface textures were analyzed: as hot rolled and cross-knurled. The hot rolled surface is the most common commercial material and is cheaper than the drawn material. The cross knurled surface was formed on hot rolled billets to simulate the roughness obtained in the phosphatization and was necessary to carry the lubricant to the tool-workpiece interface. Therefore, an average surface roughness (Ra) between 7 and 10 µm was specified to the knurled surface shown in Fig. 2-a, similar to the surface roughness characteristic of phosphated billets.

To analyze the efficiency of the lubricants used in the tests, some zinc phosphated billets with MoS_2 lubricant were extruded to represent the lubrication currently used in industries, and defined in this work as **standard tests**. Figure 2-b shows the billets dimensions, and Fig. 2-c shows the extruded dimensions in mm.



(a) (b) (c)

Figure 2. (a) Billet knurled surface, (b) billet dimensions, (c) extruded dimensions.

2.2 Lubricants

Two commercial lubricants were tested. These lubricants are mineral oils formulated with grease additives for extreme pressures. They are already used in metal forming processes on zinc phosphate coated billets. A commercial solid soap powder was also tested.

2.3 Tooling design

Extrusion tooling (Fig. 3) was designed to allow an efficient lubrication in the work zone, with a continuous supply of lubricant that is pressurized during the extrusion. Also, this tooling was designed to be easily assembled in industrial presses that currently do not use liquid lubricants. To avoid the upsetting of the billet in the inlet zone of the extrusion die, the area reduction was 22% in all extrusion tests.

2.4 Design of experiments

2.4.1 Factorial design

With the factorial design of experiments it is possible to study the effects of two or more factors and their interactions. Because of the small number of tests in the factorial design, it is recommended for the early stages of experimental design when it is necessary to define what are the significant influent factors and how they affect the results (Montgomery, 1991).

In this work four factors were investigated with a factorial design:

- heat treatment with two levels (normalized and annealed);
- surface texture with two levels (as hot rolled and cross knurled);
- lubrication with two levels (immersion and hydrostatic);
- lubricant with three levels (Two commercial mineral oils: Renoform MZA20 and Extrudoil 319MOS, and a commercial powder soap)

The extrusion load was the response variable analyzed with the statistic model proposed by Montgomery, 1991, chapter 9.

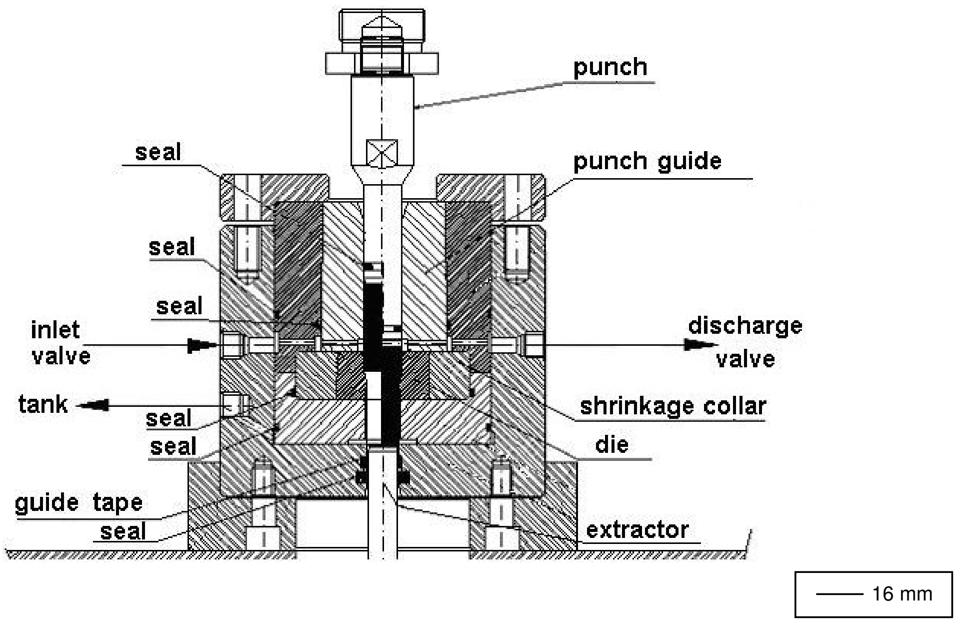


Figura 3. Experimental set up of the extrusion tooling.

2.4.2 The fixed effects model

This experimental design is recommended to analyze results with ***a*** levels for a single factor, each level tested for ***n*** replicates. In this work the lubricant was the factor analyzed, and the three levels were compared with statistical contrasts (Montgomery, 1991, chapter 3).

2.5. Cold extrusion tests

Table 1 shows the conditions of the extrusion tests carried with the experimental set up shown in Fig. 3 in a random sequence to permit the statistical analysis.

2.6. Tests with the extruded products

The surface roughness of the extruded products, and their dimensions, were measured after the extrusion tests to compare these results with those obtained from the standard tests.

Table 1. Extrusion tests conditions

Lubricant	Heat treatment	Surface texture	Lubrication	Replicate #	Test number
Renoform MZA20	Normalized	As rolled	Immersion	3	19
				2	15
				1	5
			Hydrostatic	2	17
				1	7
				3	20
		Recartilhado	Immersion	2	9
				1	2
				3	11
			Hydrostatic	3	14
				1	4
				2	12
	Annealed	As rolled	Immersion	2	16
				3	21
				1	3
			Hydrostatic	2	18
				1	13
				3	23
		Cross knurled	Immersion	3	22
				1	6
				2	8
			Hydrostatic	1	1
				2	10
				3	24
Extrudoil 319MOS	Normalized	As rolled	Immersion	3	24
				2	20
				1	17
			Hydrostatic	3	21
				1	5
				2	14
		Cross knurled	Immersion	3	19
				2	11
				1	1
			Hydrostatic	1	8
				2	9
				3	16
	Annealed	As rolled	Immersion	2	6
				3	22
				1	4
			Hydrostatic	3	18
				1	3
				2	15
		Cross knurled	Immersion	2	12
				3	23
				1	2
			Hydrostatic	3	13
				2	10
				1	7
Sabão em Pó	Normalized	As rolled	Immersion	1	7
				3	11
				2	9
		Cross knurled	Immersion	2	5
				1	4
				3	10
				3	8
	Annealed	As rolled	Immersion	1	2
				2	6
				3	12
		Cross knurled	Immersion	1	1
				2	3
				1	1
Zinc phosphate and MoS_2	Normalized	As rolled	Immersion	2	2
				3	3

3. Results and discussion

3.1 Analysis of the billets

Table 2 shows the chemical composition of the billet material measured with an electronic microanalysis device and another composition presented by the material supplier.

Table 3 shows the Brinell hardness number for the normalized and annealed billets.

Table 4 shows the results for the surface roughness of the billets with different surface textures. The thickness of the phosphate layer was also measured for the billets in the standard condition (zinc phosphate with MoS_2 lubricant) and showed values between 14 and 22 μm which is the common thickness observed in industrial cold extrusion.

Table 2. AISI 8620 chemical composition (wt. %)

	Chemical composition						
	Si	Mn	P	S	Cr	Ni	Mo
Metals Handbook, 1990	---	0.7 – 0.9	---	---	0.4 – 0.6	0.4 – 0.7	0.15 – 0.25
As measured with microanalysis	0.211	0.796	0.025	0.024	0.496	0.427	0.279
As informed by the supplier	0.22	0.71	0.015	0.012	0.42	0.42	0.18

Table 3. Brinell hardness (HB) of the billets.

Heat treatment	Process	Hardness tests conditions	HB
annealed	spheroidizing	load 312.5 N, ball ϕ 2.5 mm	116 - 124
annealed	full	load 312.5 N, ball ϕ 2.5 mm	145 - 150
normalized	---	load 625 N, ball ϕ 2.5 mm	174 - 181

Tabela 4. Average roughness Ra of the billets.

	Heat treatment/Surface texture				
	Normalized/ As hot rolled	Normalized/ Cross Knurled	Annealed/ As hot rolled	Annealed/ Cross knurled	Normalized/ As hot rolled (Standard)
Ra	2,3 – 3,6 μm	5 – 10,8 μm	2,1 – 3,5 μm	4,1 – 10 μm	3,9 – 5μm

3.2 Extrusion tests results

Extrusion tests were carried in a random sequence to validate the factorial design as described in 2.4.1 to analyze the effects of the factors on the extrusion load.

Table 5 shows the extrusion load results for each replicate (R). In that table it is also presented the interactions between the levels of the three factors: lubricants, lubrication, surface texture and heat treatment.

The analysis of variance for the factorial design with a significance level (α) of 5% presented the following conclusions:

Significant influent factors: lubricant, heat treatment and surface texture;
Non-significant influent factors: lubrication;
Significant interaction between the factors: lubricant and heat treatment, lubricant and surface texture, heat treatment and surface texture;
Non-significant interaction between the three factors together and between the factor lubrication and the factors lubricant, heat treatment and surface texture.

From these conclusions it was not considered the influence of lubrication (hydrostatic or immersion) on the extrusion load, since it was not observed its influence or interaction with another factor.

To study the influence of the different levels on the extrusion load, it was analyzed by contrast (see item 2.4.2) each level of lubricant with the different levels of heat treatment and surface texture. The contrasts were also analyzed with an α of 5% and made possible to identify the best conditions to minimize the extrusion load.

With these best conditions, new contrasts were analyzed to consider the results of the standard tests. The test conditions in Table 6 showed statistically with $\alpha = 5\%$ the same mean value of that observed in the standard tests for the extrusion load.

Table 5. Experimental results – extrusion loads (10^4 N)

	SURFACE TEXTURE								SURFACE TEXTURE							
	AS HOT ROLLED								CROSS KNURLED							
	PROCESSO DE LUBRIFICAÇÃO				**PROCESSO DE LUBRIFICAÇÃO**				**LUBRICATION**				**LUBRICATION**			
	IMMERSION				HYDROSTATIC				IMMERSION				HYDROSTATIC			
HAT TREATMENT (NORMALIZED)																
LUBRICANT	R1	R2	R3	R4	R1	R2	R3	R4	R1	R2	R3	R4	R1	R2	R3	R4
RENOFORM MZA20	13.02	13.72	14.01	-	13.03	-	13.45	-	8.12	8.45	8.72	-	8.13	9.55	9.63	-
EXTRUDOIL 319MOS	14.58	-	-	-	-	14.40	-	-	8.89	9.92	11.48	-	8.24	8.27	8.90	-
POWDER SOAP	10.94	10.84	10.80	-	-	-	-	-	9.04	8.08	8.21	-	-	-	-	-
PHOSPHATE WITH MOS_2	8.31	8.17	8.20	-	-	-	-	-	-	-	-	-	-	-	-	-
HEAT TREATMENT (ANNEALED)																
LUBRICANT	RI	R2	R3	R4	R1	R2	R3	R4	R1	R2	R3	R4	R1	R2	R3	R4
RENOFORM MZA20	8.66	-	8.06	-	9.82	8.68	9.47	-	7.30	8.24	7.87	-	7.62	7.84	8.58	-
EXTRUDOIL 319MOS	11.48	10.99	10.66	-	8.80	8.07	9.05	-	9.80	12.66	9.34	-	11.2	12.13	12.62	-
POWDER SOAP	8.82	10.23	8.39	9.57	-	-	-	-	9.91	9.94	9.81	-	-	-	-	-

Table 6. Experimental results – Mean value of extrusion loads (10^4 N).

Test conditions	Extrusion load – mean value (10^4 N)
Standard: phosphate with MoS_2 – Normalized - As rolled	8.23
Renoform MZA20 – Normalized – Cross Knurled	8.77
Powder soap – Normalized – Cross Knurled	8.44
Renoform MZA20– Annealed – As rolled	8.94
Renoform MZA20 – Annealed – Cross Knurled	7.85

The mineral oil 319MOS with the additive MoS_2 showed the worst results (higher extrusion loads) when compared to other lubricants analyzed. The test condition normalized/as rolled also showed the worst results when compared to the standard tests results. Lubricants Renoform MZA20 and powder soap with the condition normalized/cross knurled showed the best results (lower loads). Because of the ridges on the knurled surface, more lubricant could be continuously dragged and trapped in the work zone of the extrusion die.

Figures4 and 5 show the extrusion loads as a function of the process time. In Fig. 4 results show that hydrostatic and immersion lubrication with Renoform MZA20 for different test conditions presented similar results to the standard tests, except for the condition annealed/cross knurled that presented the minimum time process due to the lubricant efficiency.

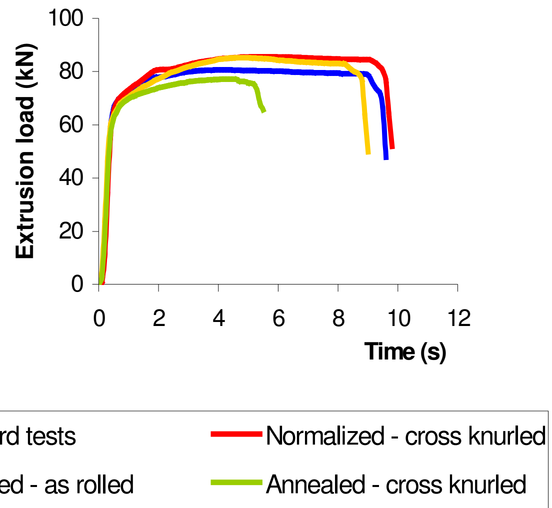


Figure 4. Extrusion load versus process time – lubricant Renoform MZA20 versus standard conditions.

Figure 5 shows that test conditions with powder soap-normalized-cross knurled presented the best results, and very similar to those found in the standard tests that represent the current industrial condition of cold extrusion.

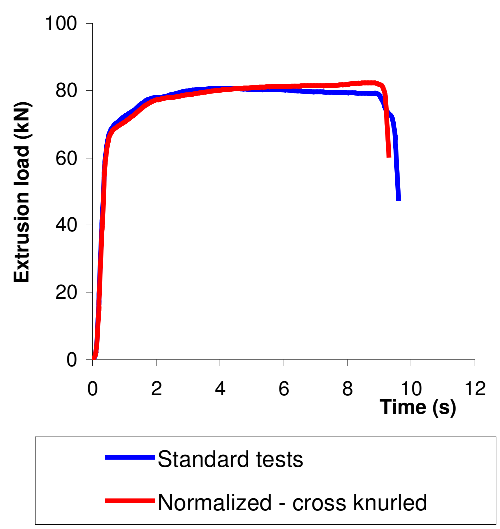


Figure 5. Extrusion load versus process time – lubricant powder soap versus standard conditions.

3.3. Results of the tests with the extruded products

All the extruded products showed diameters within the ISO tolerance IT 9 typical of cold extrusion.

Table 7 shows the results for the mean surface roughness Ra of the products extruded with the lubricants Renoform MZA20 and powder soap. These values are higher than those from the standard tests, but they represent a very good surface finish.

Table 7. Extruded products - Mean surface roughness Ra.

	LUBRICANT/HEAT TREATMENT/SURFACE TEXTURE				
	Standard tests	Renoform MZA20 Normalized Cross knurled	Renoform MZA20 Annealed As rolled	Renoform MZA20 Annealed Cross knurled	Powder soap Normalized Cross knurled
Ra	0.11 – 0.50 μm	0.44 – 2.53 μm	1.61 – 3.58 μm	0.25 – 1.94 μm	0.76 – 1.13 μm

4. Conclusions

Experimental results showed that some of the conditions used in the extrusion tests presented extrusion loads similar to those observed in the standard tests, and that these lubricants could be a good alternative for the zinc phosphate with MoS_2.

The most viable alternatives are the use of Renoform MZA20 or powder soap with a normalized/cross knurled billet. Therefore the cross knurled would substitute the phosphate as an efficient carrier for the lubricants Renoform MZA20 or powder soap preferred instead of MoS2.

Besides the low extrusion loads, the surface roughness and the dimensional quality of the products extruded with these alternative lubricants are similar to those found in the standard tests.

5. Acknowledgment

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