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Wilhelm Rehbein, Isabell Lange, Detlef Pazdzior

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Proffesional paper

SUBSTITUTION OF ZINC STEARATE IN COLD EXTRUSION PROCESSES

Abstract

Cold impact extrusion is a kind of massive forming process for the mass production of hollow or solid parts in one or more stages. Next to steel, aluminium and its alloys are the most common materials used for the production of cold extruded parts. For the lubrication of the aluminium cold extrusion process, to prevent adhesion and to reduce tool wear, the application of zinc stearate is still widely used. Because zinc stearate is a powder it has to be applied on the slugs by a tumbling process which leads to a strong dust formation. Furthermore it may cause respiratory irritation; the thermal decomposition forms toxic and irritating vapours.

This paper will present the development of a new lubricant for the cold extrusion of aluminium parts based on renewable raw materials. The new lubricant is free of zinc or other metals. Because it is a waterbased suspension, it can be applied easily and without any dust formation.

Key words: *cold extrusion, lubrication, zinc stearate, substitution, renewable*

1. Aluminium and aluminium alloys

Aluminium is the most abundant metal in the Earth's crust (8.1%), although it is not found free in nature. Pure aluminium is a silvery-white metal. It is soft, light, relatively nontoxic, with a high thermal conductivity, and high corrosion resistance. It can be easily formed, machined, or cast. Pure aluminium is soft and lacks strength, so in most cases it’s alloyed, which considerably improves its mechanical properties. The main alloying agents are copper, zinc, magnesium, manganese, and silicon. The levels of these metals are in the range of a few percent by weight.

Aluminium is nonmagnetic and nonsparking. It is second among metals in terms of malleability and sixth in ductility. The worldwide production of aluminium and its alloys exceeded in 2010 1,000,000 tons. Approximately 40% of this was primary aluminium (directly gained from aluminium oxide), 60% was secondary aluminium (from aluminium scrap). Of all metals, only iron is used more widely than aluminium.

One of the fastest growing segments of the metalworking industry is the machining of aluminium alloys. Because of the very favorable ratio of strength to density it is widely-used in aerospace applications.

A Boeing 747-400 contains 66,150 kg of high-strength aluminum [1]. The superior strength and light weight makes it also an ideal material for camping and outdoor equipment. The growing need for fuel economy and reduced greenhouse-gas emissions in automotive engineering furthermore leads to a strongly increasing demand for parts made of aluminium alloys. Due to their excellent corrosion and weathering resistance aluminium parts are also widely used in the construction and food industry as well as for household, container, marine and chemical plant applications. Finally the ratio between the density and electrical conductivity is the most advantageous of all metallic materials.

The strength and durability of aluminium alloys vary widely, not only as a result of the components of the specific alloy, but also as a result of heat treatments and manufacturing processes.

There are two main classes of aluminium alloy:

- Wrought alloys, which can be worked e.g. by rolling, extrusion, hot or cold forging into the desired form. Wrought alloys are further divided into heat treatable and non heat treatable alloys; they contain lower levels of iron, silicon, magnesium, manganese, copper or zinc.
- Cast alloys are directly cast into their final form by e.g. sand-casting, die or pressure die casting. These alloys contain high levels of silicon to improve their castability.

Aluminium and its wrought alloys can be formed very economically in cold forming processes. The achievable variation of the diameter is very large, the need of force relatively low. All wrought alloys were usually annealed before extrusion. The annealing process leads for all types of wrought alloys to a minimized hardness and to optimized strength and deformation values. Low pressing force and long tool live are the resulting advantages.

2. Cold impact extrusion

Cold forging as a general term includes processes such as extrusion, upsetting, heading, coining, or ironing used in metal forming at or near the room temperature. Cold extrusion is a forming operation where the workpiece, also called billet or slug, is pressed with high force into the deforming die. To prevent uncontrolled deformation the workpiece is supported by the extrusion container. The extrusion process therefore combines the possibility of heavy deformations with a wide choice of extruded cross sections, e.g. progressively tapered or stepwise reduced cross sections.The term “cold impact extrusion” is used especially for the extrusion of non-ferrous components under mass production conditions in high speed mechanical presses.

The advantages of the cold impact extrusion process in comparison to metal removing operations or precision forging or casting processes are the following:

- Large material savings caused by optimal utilization of the material.

- High production rates even when forming complex shapes.
- Good dimensional accuracy and high surface quality.
- Improvement of the material properties by taking advantage of the cold work hardening and favorable microstructure.

The processes of cold extrusion are classified depending on the direction of material flow in relation to the tool movement direction, e.g. forward, backward and lateral. Additionally the processes are categorized according to the shape of the manufactured workpiece, i.e. solid or hollow.

2.1 Solid forward impact extrusion

A solid forward impact extrusion process consists on the following operational steps (figure 1):

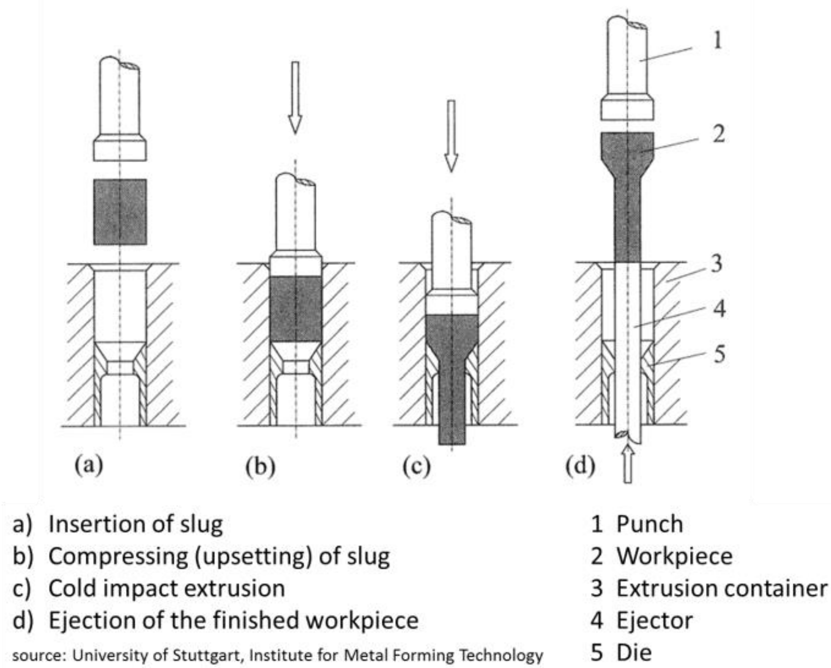


Figure 1: Schematic illustration of a forward solid extrusion process [2]

- The material is first pressed into the holder so that it fills out the cavity.
- The continued stroke of the punch then causes the material to flow in the direction of the punch movement into the die.
- After the forming operation, the workpiece is removed by an ejector mechanism.

2.2 Cup backward impact extrusion

In a hollow (or cup) backward impact extrusion operation the punch is forced into the forming material which is radially enclosed by the extrusion container (holder). An ejector punch builds the bottom of the container. The material flows through a gap between the punch and the extrusion container contrary to the direction of the punch movement (figure 2).

2.3 Lubrication of cold impact extrusion processes

For all the different cold impact extrusion processes the correct application of a suitable lubricant is essential.

An insufficient amount of lubricant causes an inadequate flow of the material; the desired shape of the workpiece will not be generated. Furthermore, the imperfect separation properties of the lubricant film can cause adhesion of workpiece material on the punch or die.

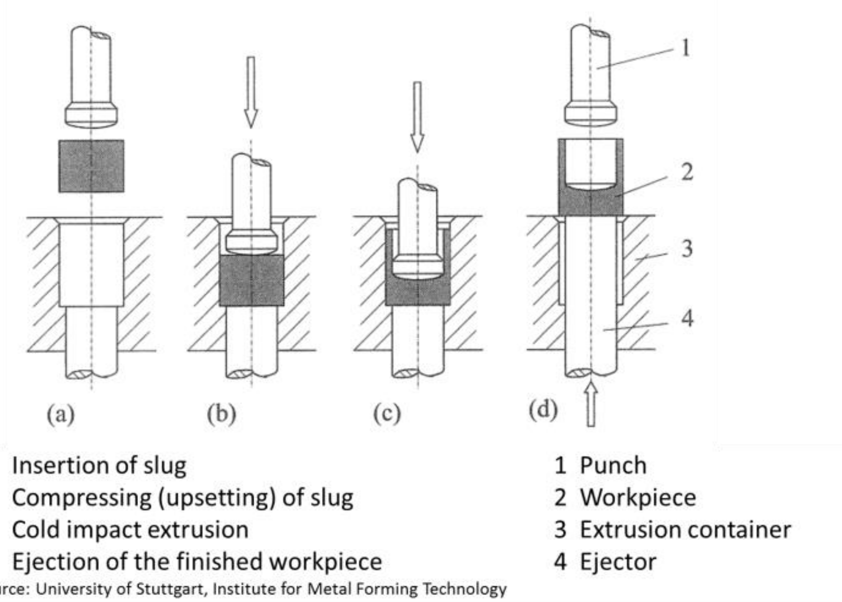


Figure 2: Schematic illustration of a backward cup extrusion process [2]

This can lead to the sticking of the workpiece in the die. On the other hand, too much lubrication, e.g. by the application of an excessive amount of lubricant, or by the use of an improper lubricant, will cause a too rapid flow of material. This often results in an orange skin-like rough surface (figure 3). Finally, an unevenly-applied lubricant film also leads to an unevenly shaped workpiece.

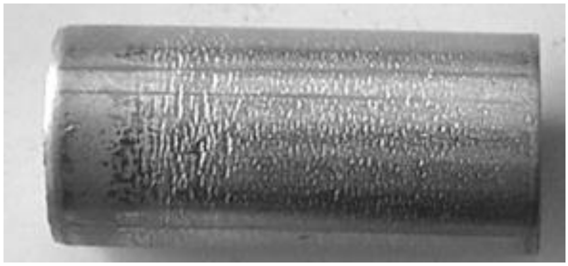


Figure 3: Surface roughness, caused by excessive lubrication
Source: Forschungsgesellschaft Umformtechnik

3. Tests with different lubricants

3.1 Zinc stearate

For most of the aluminium cold extrusion processes zinc stearate is used as lubricant. Zinc stearate is a white powder with a very low density of approximately 1.1 g/cm³. It is widely used in cold extrusion processes because it works very well as a solid lubricant and mold release agent. It is applied on the slugs before extrusion by a tumbling process. Because of the low density of the powder there is a strong dust formation when using zinc stearate although there are usually exhaust systems installed (figure 4).

Figure 4: Zinc stearate residues at a tumbler

The dust however can cause irritation of the skin, eyes and the respiratory tract. There is also the risk of a dust explosion caused by electrostatic ignition. At a thermal decomposition toxic and irritating vapors are formed. To prevent the negative effects of zinc stearate a research project was started to develop a new lubricant with comparable lubricating properties but lower toxicity and possibly without the problem of dust formation.

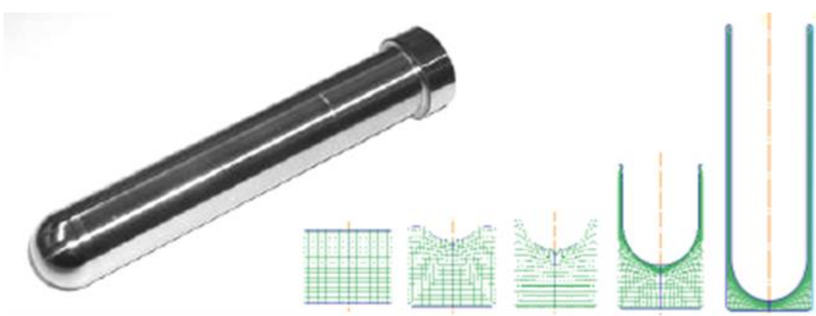
3.2 Testing of alternative lubricants

The desired properties of a lubricant for aluminium cold impact extrusion are the following:

- Formation of a stable lubricant film with high pressure absorption capacity and good adhesion properties within the temperature range of the cold forming process.
- Realization of low pressing force, low tool wear and high surface quality of the manufactured parts.
- No sticking of the coated slugs, no accumulation of residues on the tool.
- Easy application and homogeneous distribution of the lubricant.
- Low toxicity, no content of heavy metal.
- Universal applicable for all kind of aluminium alloys.
- Easy to remove, low ecological impact.

3.3 Backward cup extrusion test

The first tests with different kind of lubricants were carried out at the Institute for Metal Forming Technology of the University of Stuttgart. For these tests a backward cup extrusion process was chosen on a Müller-Weingarten hydraulic press with a maximum pressing force of 2000 kN. A punch with a hemispherical shaped end was used to form the cup from the slug, increasing the overall surface area by the factor 7.9 (figure 5).



source: University of Stuttgart, Forschungsgesellschaft Umformtechnik

Figure 5: View on the punch and drawing of the material flow of the backward cup extrusion process

All lubricants in this first test were liquids, based on vegetable esters. They contained different types of extreme pressure (EP) and anti-wear (AW) additives like sulfurized esters or olefins, zinc dithiophosphates and ashfree di-thiocarbamates (table 1). The lubricants were applied on the slugs by spraying.

Table 1: Composition of the lubricants in the backward cup extrusion test

	Base oil	Additives
A	Ester	AW-additive, low reactivity
B	Ester	EP-additive, high activity
C	Ester	EP-additive, medium activity, high lubricity
D	Ester	EP-additive, low activity, very high lubricity
E	Ester	AW-additive, medium reactivity

Independent of the additive type, all tested lubricants showed an insufficient material flow. Compared to the cups manufactured with zinc stearate, the walls of the extruded cups were not correctly shaped, the heights were too low. Also the increased pressing force indicates the lack of material flow (figure 6). Additionally there was a lot of material adhesion observed on the punch and die. These test results lead to the assumption that liquid lubricants are not suitable for this cold impact extrusion process because the lubricant film will be squeezed out under high pressure. Thus the further tests were done with formulations containing solid lubricants.

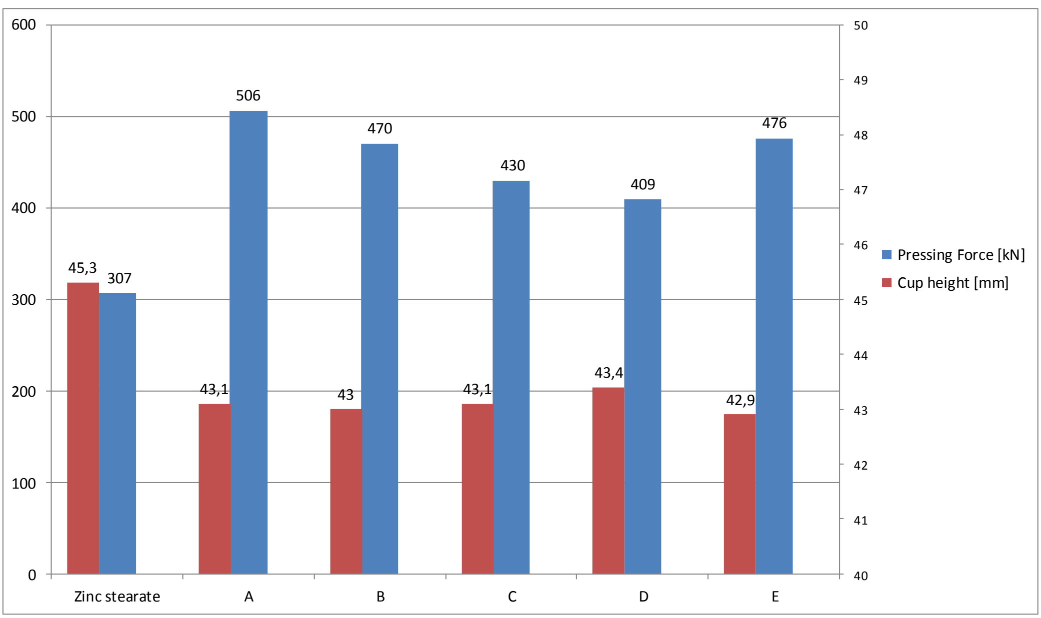


Figure 6: Results of the backward cup extrusion test

3.4 Spike-test

In a second test row at the Institute for Metal Forming Technology a completely new kind of lubricant was tested. This lubricant consists on solid particles derived from renewable raw materials which are dispersed in water. The slugs were made of the aluminum wrought alloy EN AW-6082 which contains silicon, magnesium and manganese as alloying elements. It is an alloy with high strength and very good corrosion resistance. The parts were heat treated for good cold formability.

For a consistent material flow it is very important that the lubricant can be applied on the slugs as a very thin and homogenous film. This was done in the same manner than when using zinc stearate, i.e. by tumbling. For every test of this row 5 slugs were placed into a plastic bottle which was connected to a tumbler. By means of a syringe it was possible to add the lubricant suspension in a low amount and exact dosage to the slugs (figure 7).

For achieving an even distribution of the lubricant on the non symmetrical shaped slugs some steel balls were added to the bottle. After tumbling for 15 minutes the water was completely evaporated and an extremely thin lubricant film covered the slugs. The best spike-test results regarding material flow, surface quality and tool cleanliness were achieved with a residual lubricant film of approximately 0.025 mg per mm² slug surface. Previous tests at the Institute for Metal Forming Technology showed that when using zinc stearate as lubricant on the same slugs, the best results were achieved with an amount of approximately 0.04 mg per mm².

Figure 7: Application of the lubricant dispersion

Because of its high validity as a simulation test for cold extrusion processes and its good repeatability the spike-test was used for this test row. This test combines an upsetting process with a forward extrusion process.

A cylinder shaped slug with a conical extension on one side is pressed into a die, forming a spike (figure 8). Again the Müller-Weingarten hydraulic press with a maximum pressing force of 2000 kN was used for this test. The die was made from a nitrided powder tool steel which does not need an additional surface coating. The polished tool surface causes very low friction and reduces adhesion of the workpiece material.

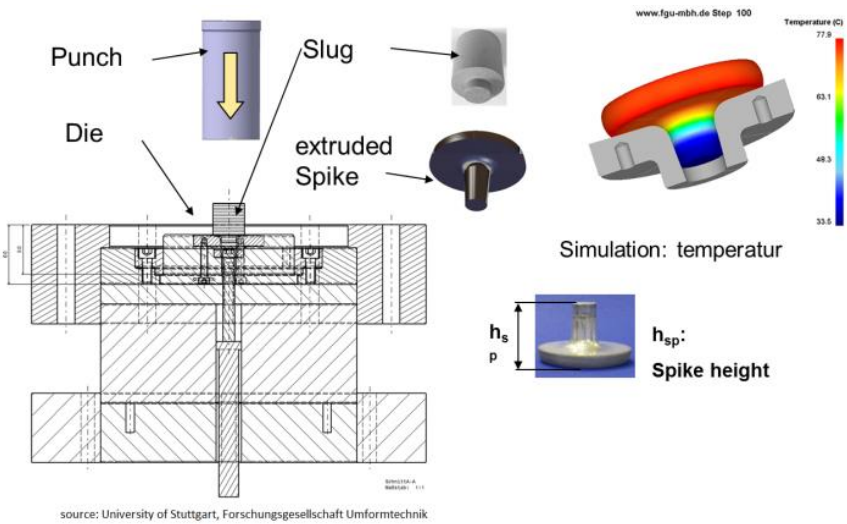


Figure 8: Design of the slug, the spike-test tool and the cold extruded spike

The evaluation of the test results was carried out by using the following parameter:

- The spike height gives an indication of the material flow.
- The pressing force which is needed for the cold impact extrusion process.
- The temperature of the spikes after the extrusion process.
- The adhesion of workpiece material and the formation of lubricant residues in the die.

In particular the material flow properties of the new lubricant have to be similar to those of the zinc stearate to avoid the expensive reconstruction of the cold extrusion tools. Parameters for assessing the material flow are the height of the produced spikes and also the temperature of the parts measured directly after the extrusion process. The pressing force should also be at the same or a lower level in order to save energy and to avoid exceeded tool wear. Also the presence of lubricant or workpiece material residues in the die has a bad influence on the surface quality of the formed parts and leads to the necessity for a frequent revision of the die.

Two modifications of the lubricant dispersion containing different solid lubricant particles were tested by using the spike-test (figure 9).

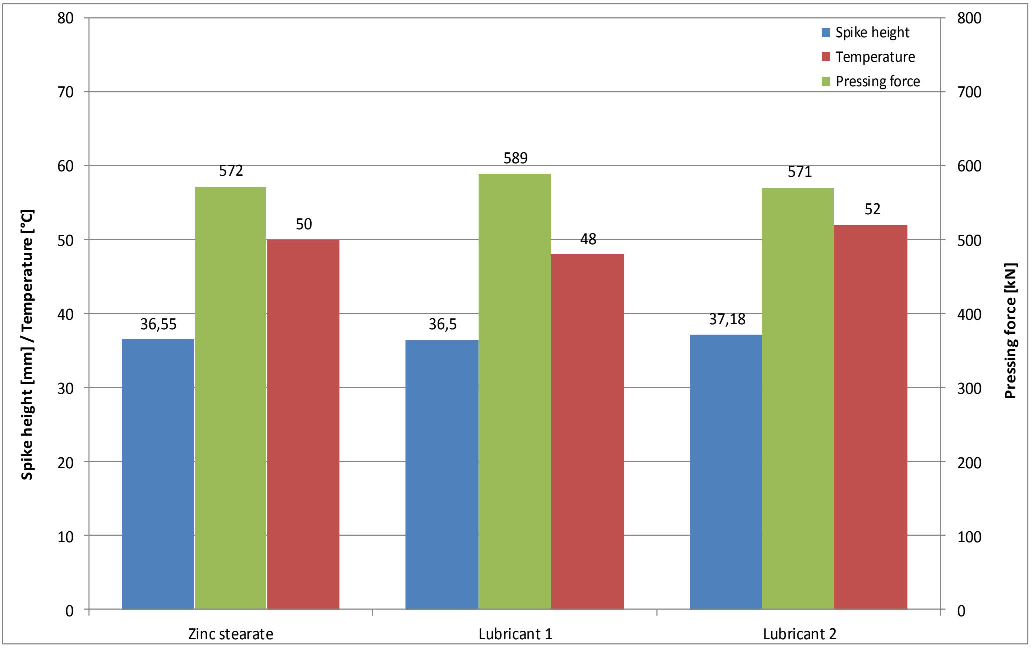


Figure 9: Results of the spike-test

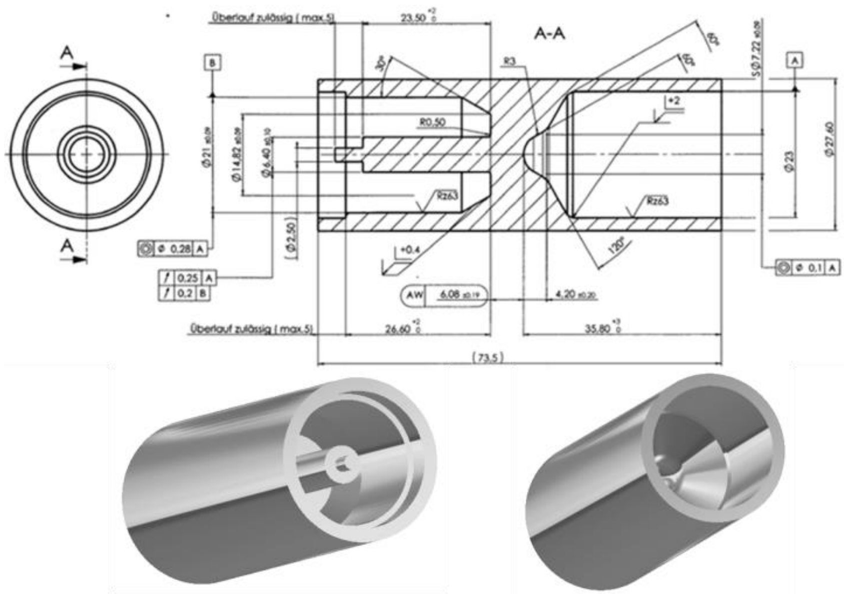
Compared with zinc stearate the spikes produced with lubricant 1 showed nearly the same height. The temperature of the spikes after the cold extrusion process was slightly reduced however the pressing force was slightly increased. The tests with lubricant 2 showed nearly the same pressing force than the tests with zinc stearate but the temperature of the parts was slightly higher. Also the spike height was higher which indicates an increased material flow. Additionally lubricant 2 clearly formed residues in the die, the surface quality of the produced spikes was lower (figure 10). Taking the spike-test results into account lubricant 1 was selected for further testing.

3.5 Testing under production conditions

To check the properties of the lubricant under real production conditions the next test took place at an aluminium processing company which is focused on the production of cold impact extrusion parts. A quite challenging part in this company is the DK-piston (figure 11) which is manufactured from a slug in one step in a combination of a forward solid and forward cup extrusion process and a backward cup extrusion process with variation of pressing speed and pressing force.

The slugs were made from the aluminum alloy EN AW 6082 and had a hardness of 43 HB. The slug weight was 0.060 kg, the surface was 4,290 mm². Again the slugs were tumbled for 15 minutes together with some steel balls to achieve a homogenous distribution of the lubricant film. 210 slugs were pressed with lubricant 1. Additionally 140 slugs were manufactured by using the lubricant 1a which is a modification of lubricant 1 containing a special EP-additive with high lubricating properties.

Figure 10: Surfaces of the cold impact extruded spikes:
left by using lubricant 2, right with lubricant 1



source: University of Stuttgart, Forschungsgesellschaft Umformtechnik

Figure 11: Drawing and pictures of the DK-piston

The tests were done on a Dunkes hydraulic press using a pressing force of maximum 270 kN, the maximum pressing speed was 60 mm/sec. Again the maximum pressing force was measured by a measuring device at the press. The shell temperature of the pistons was measured directly after the extrusion process by means of a pyrometer. The test results (figure 12) show that the temperature of the extruded parts which were manufactured with lubricant 1 was slightly lower than for those which were produced with zinc stearate. A further slight reduction of the temperature was observed for lubricant 1a. The pressing force with the lubricants 1 and 1a was up to 2.2% higher than with zinc stearate.

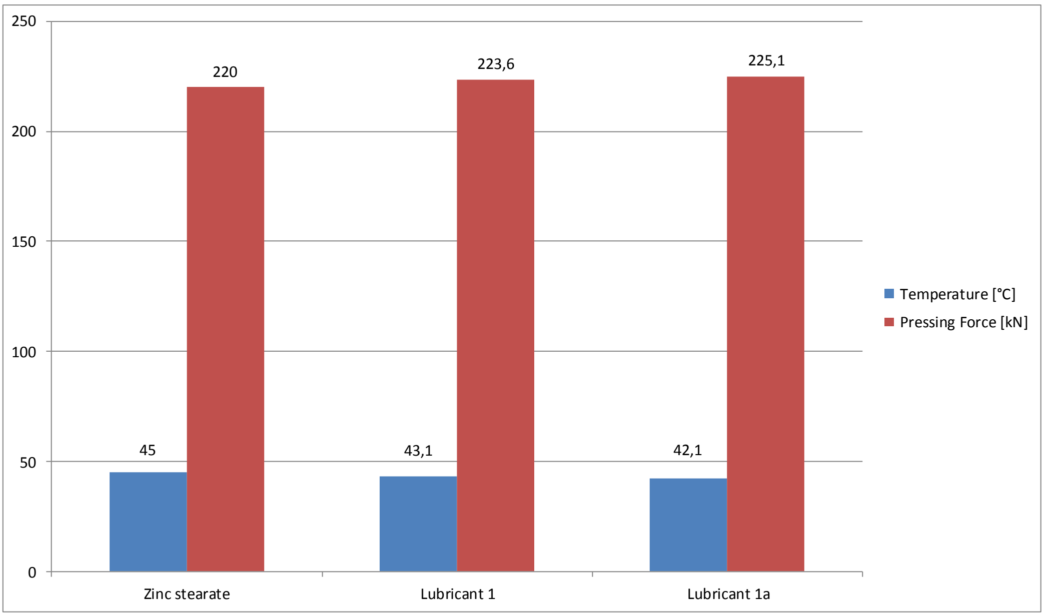


Figure 12: Recorded mean temperatures and pressing forces of the DK-piston test

For both lubricants the material flow and the surface quality was very good. The inner surfaces of the pistons looked even shiny (figure 13). Also there was no adhesion of aluminium at the tool. In comparison to zinc stearate there was less lubricant residue at the punch and the die which was easily removable by wiping.

For lubricant 1 the best results were realized with a lubricant film of approximately 0.0016 mg per mm². With lubricant 1a it was possible to reduce the amount of lubricant even more: to approximately 0.0011 mg per mm². When using zinc stearate an amount of approximately 0.0023 mg per mm² was needed for an optimal material flow.

Figure 13: DK-pistons extruded with lubricant 1

4. Conclusion

The test results show that it is possible to substitute zinc stearate as lubricant in aluminium cold impact extrusion processes by a suspension of a solid lubricant in water. This new lubricant formulation has the following advantages:

- Based on organic substances from renewable resources.
- Forms a very thin, homogeneous lubricant film.
- Material flow is similar to zinc stearate.
- Less residue on the tool.
- Suspension in water, no dust formation, easy and precise application.
- Easily removable by washing.
- A further improvement of forming performance by additional additives is possible.

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Authors

Wilhelm Rehbein; e-mail: wilhelm.rehbein@rheinchemie.com
Isabell Lange; e-mail: Isabell.Lange@lanxess.com
Detlef Pazdzior
Rhein Chemie Rheinau GmbH, Mannheim, Germany

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ZAMJENA CINKOVA STEARATA U PROCESIMA HLADNE EKSTRUZIJE

Wilhelm Rehbein, Isabell Lange, Detlef Pazdzior

Sažetak
Hladna ekstruzija (isprešavanje, udarno istiskivanje) je široko upotrebljavani proces oblikovanja proizvoda široke potrošnje šupljeg ili punog presjeka, koji se provodi u jednom ili više koraka. Najčešće se ovim procesom proizvode dijelovi načinjeni od čelika, aluminija i njihovih slitina. Kako bi se spriječila adhezija i smanjilo trošenje kod hladnog istiskivanja aluminija za podmazivanje se još uvijek često koristi cinkov stearat. Kako je cinkov stearat praškast na tablete ga se nanosi vrtloženjem što izaziva stvaranje prašine. Također, to može izazvati dišne smetnje; toplinska razgradnja izaziva otrovne i nadražujuće pare. U ovom radu se govori o razvoju novog maziva za hladnu ekstruziju aluminijskih dijelova, na osnovi obnovljivih sirovina. Novo mazivo ne sadrži cink ili druge metale. Riječ je o vodenoj suspenziji koja se može jednostavno primjenjivati bez stvaranja prašine.

Ključne riječi: *hladna ekstruzija, podmazivanje, cinkov stearat, zamjena, obnovljiv*