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The Structure and Mechanical Properties of an Aluminium A356 Alloy Base Composite With Al_2O_3 Particle Additions

RESEARCH

Composites-castings with an aluminium A356 alloy base and additions of 1, 2, and 3 % (wt.) of Al_2O_3 reinforcement of 12µm size were made. A side by side investigation of the microstructure and hardness of the composite and the base alloy cast into a steel mould was done. According to hardness values samples of A356 + 3 % Al_2O_3 composite with a particle size of 12µm were selected. These samples were additionally pressed in a special tooling by which tensile test samples were obtained. Application of the compocasting process led to a transformation of a dendritic to a nondendritic structure of the base alloy. The mechanical properties of the composite are improved in relation to the base alloy.

Keywords: A356 alloy; composites; compocasting

INTRODUCTION

A356 belongs to a group of hypo eutectic Al-Si alloys and has a wide field of application in the automotive and avionics industries. It is used in the heat treated condition in which a optimal ratio of physical and mechanical properties is obtained [1]. The alloy solidifies in a broad temperature interval (43 ºC) and is amenable to treatment in the semi solid state as well as casting [2,3]. For this reason it is the subject of rheological investigations [4], as well as methods of treatment in the semi solid state [3,5]. By these methods it is possible to obtain castings with reduced porosity of a non dendritic structure and with good mechanical properties. Besides this the A356 alloy is used as a matrix for obtaining composites [6], which have an enhanced wear resistance, favourable mechanical properties at room temperature and enhanced mechanical properties at elevated temperatures.

A356 solidifies in a wide enough temperature interval between the solidus and liquidus temperatures that it can be used as a matrix for obtaining composites by the compocasting method. In this work for obtaining a composite unmodified A356 alloy was used so as to evaluate the effect of added particle strengthener on the structure and mechanical properties of the composite without modification effects. The results of preliminary mechanical tests on the obtained composite were compared with the known values of mechanical properties of a commercial modified heat treated A356 alloy [8].

EXPERIMENTAL

For this experiment an A356 alloy of the chemical composition shown in Table1 was used.

Before making the composite an A356 cylinder of 12 mm diameter and 100 mm height was cast into a cold graphite mould out of which samples for metallographic examinations and hardness measurement were made. The composites were made by the compocasting method using mechanical mixing of the matrix i.e. the A356 alloy which was previously bought into the semi solid state and addition (infiltration and admixing) of particles of the strengtheners. Addition of Al_2O_3 powder particles of a average size of 12 µm was done in quantities of 1, 2 and 3 wt. % respectively.

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Table 1. Chemical composition of A356

Element	Si	Cu	Mg	Mn	Fe	Zn	Ni	Ti	Al
Wt. (%)	7.20	0.02	0.29	0.01	0.18	0.01	0.02	0.11	Balance

The apparatus for the compocasting method is shown in Fig. 1. It is made up of a laboratory electric resistive 2 kW furnace (with additional temperature control equipment) and a mixer. The crucible inside the furnace was made by a special procedure out of alumina and has an opening in the wall for introducing a thermocouple to 20 mm from the bottom of the crucible. It was possible to record and change the number of revolutions of the mixers shaft (Fig.1). The active part of the mixer is platelike whilst the ratio of the circle which the mixer traces to the inner diameter of the crucible is 0.53.

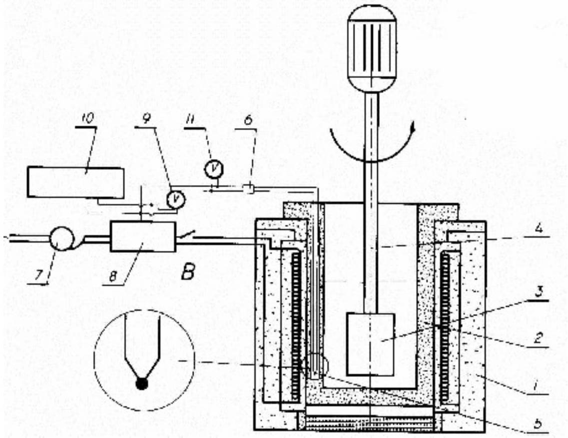

Fig. 1. Apparatus (1), Resistive furnace (2), Crucible (3), Mixer (5), Thermo couple (6 to 11) and Measurement and regulation

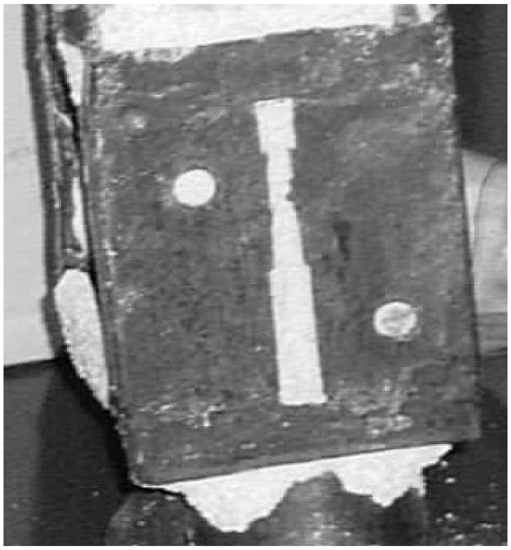

Fig. 2. Tooling for pressing the composite

The experimental work irrespective of the amount of added strengthener particles encompassed preparation of the melt, infiltration of stengthener particles and mixing of the semi solid melt with the infiltrated stengthener particles. The preparation of the melt was done by heating and melting of the melt (A356 alloy), overheating of the melt to 650 ºC (30º above the liquidus temperature) for cleaning the slag and cooling to 605 ºC (26 wt. % of solid phase).Then a mixer was introduced into the semi solid melt and mixing was done with a speed less than the one proscribed. With uninterrupted mixing the semi solid melt was heated to a temperature of 600 ºC (33 wt. % of solid phase), i.e. to the working temperature. The mixing intensity was then increased to the planed rpm of the mixer (500 rpm) after which a premixing of the semi solid melt for 5 minutes was done with a goal of breaking up the dendrites. Infiltration of the powder was done in a 5 to 7 minute period depending upon the quantity of particles. After infiltration an additional mixing was done with 30 minute duration to enhance the strengthener particle distribution. Afterwards the semi solid melt of the composite was poured into a prepared heated (500 ºC) steel mould where manual pressing was done until metal drops appeared at the mould joints. Cylindrical castings-rods were obtained, of 36 mm diameter and 150 mm height from which test samples for metallographic investigation and hardness measurements were machined. Test samples for tensile testing and tribological examinations were obtained by additional pressing. A special tooling made out of IN100 shown in Fig. 2 was used.

A characterization of the obtained composite samples included metallographic examination, measurement of hardness and preliminary tensile testing.

Heat treatment of a small number of composite samples according to the treatment proscribed for the commercial A356 alloy was done. This treatment encompasses a solution anneal for 6 hours, quenching in water followed by artificial ageing for 6 hours and air cooling. This procedure was used as a test just to evaluate the values of the basic mechanical indicators (without additional metallographic characterization of the samples).

RESULTS

Fig. 3 (magnification 200 x) shows the results of the metallographic investigation. The structure of base unmodified alloy is dendritic (Fig. 3a). Under the influence of the shear forces caused by the rotation of the mixer a transformation of dendritic to a non dendritic structure of the primary α phase particles took place. Large elliptically shaped primary particles are formed (Figs. 3b, 3c and 3d) and a coarsenining of the structure is obvious. An overview of the morphologies in Figs. 3b, 3c and 3d shows that the strengthener particles are not only placed in the in the eutectic zone but are infiltrated in the primary particles as well. The hardness measurement results are shown in table 2. The values for the hardness of composites with 1 and 2 wt. % particle strengthener differ only a little while a significant increase in hardness is observed with a 3 wt. % particle strengthener. If values of hardness of the composite are compared to the values of hardness for the sample made from the cylinder cast into the graphite mould (72 HV) it is observed that only the value of the hardness of the composite with 3 wt. % Al_2O_3 exceeded this value. Also an additional increase in hardness after heat treatment was observed.

Table 2. Hardness of composite materials

Composite (A356)	1 % Al_2O_3	2 % Al_2O_3	3 % Al_2O_3	3 % Al_2O_3, H.T.
Hardness ($HV_{50\ gr}$)	62.4	62.9	72.5	78.8

Chosen samples of the composite with 3 wt. % Al_2O_3 were subjected to preliminary tensile testing. The average value of tensile strength of composite samples is 190 MPa, while for the heat treated samples it is 211 MPa.

DISCUSSION

The solidification of alloy A356 according to the equilibrium phase diagram [2] commences at 620 ºC by the separation of aluminium rich primary α phase. At 577 ºC an eutectic transformation takes place when the rest of the melt solidifies into a two phase eutectic mixture. At the end of solidification the structure of the A356 alloy consists of primary particles of α phase and a eutectic in the space between the particles. The size and the shape of the separated silicon particles determine the morphology of the eutectic which has a great effect on the mechanical properties of the alloy. The appearance of the eutectic primarily depends upon the cooling rate and impurities present in the alloy.

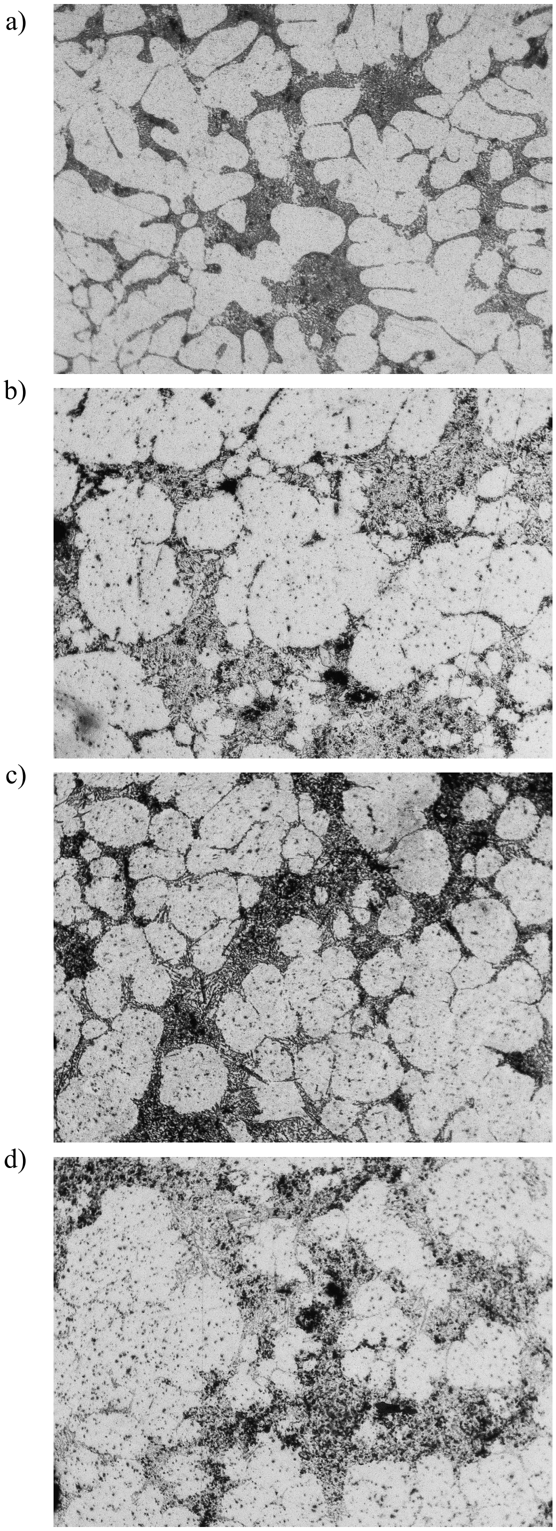

Fig. 3. Microstructure of A356 and a composite based on it: a) A356 cast into a graphite mould, b), c) and d) Composite A356 + 1, 2 and 3 wt. % Al_2O_3 (12 μ particle size)

When casting with high cooling rates of the melt the structure of A356 alloy consists of primary particles of a dendritic shape with a eutectic in the interdendritic space with rodlike silicon particles [7]. The structure shown in Fig. 3a for the sample made from the cylinder cast into a cold graphite mould complies with this above mentioned structure. Nondendritic structures (Figs. 3b, 3c and 3d) obtained as a result of the mixing during the compocasting procedure lead to the fact that under the previously described experimental conditions a transformation from a dendritic to a nondendritic structure took place. With lower and middle mixing speeds which are used for the compcasting procedure (with infiltration of the particle strengthener) it is not possible to obtain the desired fineness of the structure as opposed to fine elliptic-circular particles which it is possible to obtain at high mixing speeds by applying the popular thixocasting procedure (without strengthener). I.e. at great mixing speeds under the effect of centrifugal force particles of strengthener concentrate along the peripheral parts of the casting, segregations at a macro level form and the distribution of the strengthener is uneven. Because of the requirement for an even distribution of the strengthener trough the whole volume of the composite with a fine structure at the same time, the design of the morphology of composite structures using the compocasting procedure represents a formidable research task. Infiltration of strengthener particles into the space of primary particles (Figs. 3b, 3c and 3d) which appear under the liquidus temperature and during mixing are present with nearly 40 wt. % is obviously the result of collisions (interactions) of primary particle-stengthener particle. The other part of the strengthener particles is placed in the eutectic zone, so that it is made up of mixed particles of strengthener (Al_2O_3) and Si particles in an Al rich α-phase matrix.

In the composite with 1 and 2 wt. % Al_2O_3 the primary particles are about the same size in the shape of statistically distributed aggregates separated by a narrow eutectic zone. In the case of the composite with 3 wt. % Al_2O_3 a further agglomeration is noticed which indicates an excess mixing time. This fact can be used in further work to optimize the mixing process parameters. A comparison of the results of mechanical testing (i.e. a hardness value of 72.5HV and tensile strength of 190 MPa) with the values for modified heat treated aluminium alloys with lower magnesium content [8] shows that the mechanical properties of the obtained composites are comparable to the values for modified heat treated Al-Si alloys of appropriate composition. This gives encouragement for further work in both the making of composites with a greater content of strengthener as well as in the improvement of the properties of the obtained composites by heat treatment. The values of the mechanical properties of heat treated composite samples (hardness of 78.8 HV and tensile strength of 211 MPa) indicate a certain improvement but are lower than expected. It is possible that the applied heat treatment used for commercial castings of A356 led to over ageing of the sample. It is known that strengthener particles accelerate the ageing process [9] so it is necessary to further investigate this effect and modify the heat treatment.

CONCLUSION

Based on the previous it can be concluded that:

Composite castings with an A356 alloy matrix with additions of Al_2O_3 particles with a size of 12 μm have been made.

By the compocasting method a non dendritic microstructure with elliptical primary particles has been made.

A favourable distribution of strengthener particles in the matrix has been achieved.

A favourable combination of mechanical properties in the composites is obtained in this phase of work.

ACKNOWLEDGEMENTS

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ISPITIVANJE I KONTROLA METALNIH POLUFABRIKATA I DELOVA

ISPITUJU SE KARAKTERISTIKE ZAHTEVANE STANDARDIMA
ZA IZRADU I ISPORUKU ZA POLUFABRIKATE,
ILI ZAHTEVANE KONSTRUKTIVNOM DOKUMENTACIJOM
ZA DELOVE I SKLOPOVE

- HEMIJSKI SASTAV
- MEHANIČKE KARAKTERISTIKE
- MEHANIČKO TEHNOLOŠKE KARAKTERISTIKE
- METALOGRAFSKE KARAKTERISTIKE
- ISPITIVANJE BEZ RAZARANJA

ISPITIVANJE I KONTROLA NEMETALNIH MATERIJALA I DELOVA

GORIVA
MAZIVA
ULJA
SREDSTAVA ZA HLAĐENJE MOTORA
KOČIONIH TEČNOSTI
BOJA
LEPKOVA
ZAPTIVNIH MASA
GALVANSKIH I HEMIJSKIH PREVLAKA
GUME
PLASTIKE I
DRUGIH NEMETALA

OSTALE USLUGE:

RAZVONO ISTRAŽIVAČKI RAD NA UVOĐENJU NOVIH MATERIJALA I TEHNOLOGIJA; ISPITIVANJE ZAVARENIH SPOJEVA I PROVERA STRUČNE OSPOSOBLJENOSTI ZAVARIVAČA; MOTORNI TESTOVI ZA ISPITIVANJE RAZNIH MATERIJALA I FLUIDA

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D. ADAMOVIC, M. STEFANOVIC, M. ŽIVKOVIĆ, F. ŽIVIĆ

RESEARCH

Investigation of Influence of Tribological Conditions on Friction Coefficient During Multiphase Ironing for Steel and Aluminium Sheet Metal

At cold plastic forming, the size of contact surface changes during the process, which means that parts of material which were not in contact in the previous phase now get in contact with the tool. This condition, as well as many others, create a series of specific problems, such as: change of friction coefficient in conditions of plastic forming, significance of tool roughness and its interaction with initial and then variable roughness of material being formed, and also prominently large differences in their mechanical properties, development of the wearing process and potential local welding (appearance of "galling"), possibility and quality of lubrication, etc.

If it is necessary to achieve the larger strain ratio during the ironing process, which would be possible without interoperation glowing, then the drawing is performed through many dies in succession. Thereat, due to the change of contact conditions (dislodging of lubricant, change of surface roughness, formation of diffusion and adhesion junctions), the friction condition change as well.

The aim of the experimental researches carried out in this paper was to indicate the changes friction coefficients which occur at multiphase ironing and to consider the influence of some factors (tool material, lubricant on die and punch) onto the process development.

Keywords: Multiphase ironing, friction coefficient, sheet metal

1. INTRODUCTION

Ironing is applied in manufacture of cylindrical pieces in which the depth is larger then diameter, and bottom thickness is larger than wall thickness, such as bushes, thin-wall pipes, shock absorber casings, fire extinguishing devices, gas balloons, oil filters casings, screeds of piston engine cylinders and especially food and drink tin cans whose annual world production amounts to a billion of pieces. The aforementioned pieces are made of materials which have the sufficiently large plasticity in cold state, such as low carbon steels, austenite stainless steels, aluminum, brass and others. During the last few years, this method of forming found its application in electro-optical industry as well, in production of optical and magnetic discs for obtaining the mirror surface, since this method is considerably cheaper then mechanical treatment.

The initial shape of the piece which is being ironed should have the cylindrical box shape which is obtained by deep drawing or opposite-direction pressing out. The piece obtained in such a way is being drawn further through one or more dies until it obtains the final shape.

In order to achieve the proper reduction of wall thickness, the drawing can be performed through many dies simultaneously (die block) or through one graded die. This is possible only in case when there is no need for inter-glowing. Multistage drawing is much more economical then single stage drawing.

In the process of forming by ironing, the tribological conditions, i.e. realized friction forces, play the significant role. Stress-strain condition of plastically formed piece, the possibility for successful forming, as well as the force needed for performance of forming depend on the size and distribution of contact stresses. Since metal

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forming takes place in conditions of high contact pressures, the absence of lubricant in such conditions would lead to the direct contact of forming material and tool, i.e. it would lead to micro welding or adhesion of the softer material onto the harder tool, and thus to significant disturbance of forming conditions [7].

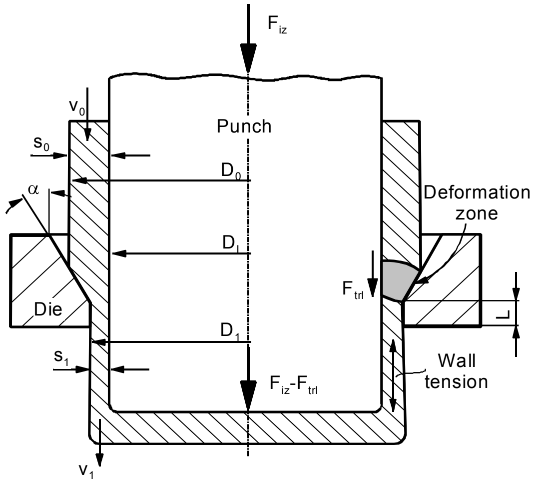

Figure 1: Scheme of ironing

The process of ironing through single die is shown schematically in Fig.1, with general outline of friction forces in contact of piece and die, i.e. punch. The effects of friction forces in forming zone are different: on the outer surface (between piece and die) these forces (F_{trM}) increase tension stresses, and on the inner side (between the piece and punch), forces (F_{trI}) disburden the critical section reducing the stresses in the wall of the piece being ironed. That is the main reason for achievement of high strain ratios and realization of significant growth of relative depth at drawing.

Ironing is performed in conditions which are similar to plane forming state. The increase of friction on the side of the punch reduces the critical tension stress, but the total ironing force increases. Thereat, the force F_{trI} must not increase so much that it brings to the appearance of rough infringements and micro welding of work piece metal particles onto the tool, which would cause the damage of work piece and tool and would make difficult the removal of work piece from the punch.

It is clear that the influence of tribological conditions at ironing is extremely important and it has been the subject of researches of many researchers during the past years, both in real processes and on tribo-models. The investigation of tribological conditions in real processes takes much more time and is considerably more expensive; therefore, investigations on tribo-models are more often practiced.

Modeling of tribological conditions at ironing implies the satisfying of the minimum of necessary criteria, with regard to: similarity in stress-strain characteristics, in temperature-velocity conditions, in properties of tool and material surface and in state of their contact during forming.

In literature, it is possible to find the whole series of tribo-models which were mainly developed for particular purposes [1, 2, 3, 4, 5 and 6]. The mutual property of all models is that they do not completely imitate the real process of ironing regarding tool geometry, stress-strain state or contact state during forming. For most of the illustrated models it is not possible to determine the friction force, i.e. coefficient of friction between work piece and punch, which has the extreme importance in the ironing process, as we have previously mentioned. Also, for most of the models, the angle of die cone is not taken into consideration etc. All this indicates that suggested models have limited application, which should be taken into consideration when using the data obtained by applying them [8].

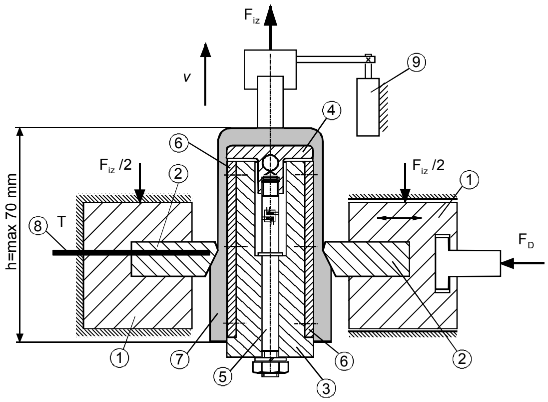

Figure 2: Scheme of the model used in this paper

1. Die support, 2. "Die", 3. "Puncs" body,
4. "Punch" front, 5. Gauge with measuring bands,
6. Plates, 7. Sheet metal band (test piece),
8. Thermocouple, 9. Potentiometer travel gauge

Taking into account the advantages and disadvantages of the specified models and taking into consideration the objective possibilities, in this paper we have proposed one new tribo-model of ironing, which bilaterally symmetrically imitates the zone of contact with die and punch. This model allows the realization of high contact pressures and takes into account physical and geometrical conditions of the real process (material of die and punch, topography of contact surfaces, angle of die cone etc.) [9]. The scheme of mentioned tribo-model is given in Figure 2.

Bent sheet metal band 7, in the U shape, (test piece), is assembled on the punch. It is affected upon by “dies” 2 with force F_D. The dies are assembled in supports, whereat the left support is immovable, and the right support is movable together with the die. The punch consists of the body 3 and front 4 which are interconnected with gauge with measuring bands 5.

The test piece is moved (it slides) between dies, by action of force F_{iz}, onto the punch front, whereat the thinning of test piece wall thickness occurs. While the test piece is moved, it's outer surface slides against die surface, and the inner test piece surface slides against plates 6 which are fixed onto the punch body.

The device is realized with compact construction of increased stiffness, with possibility for simple alteration of contact-compressive elements (die 2 and plate 6), with simple cleaning of contact zones and convenient assembling of test pieces.

Plates 6 and die 2 can be made of various materials and with various roughnesses, and dies can be made with various slope angles as well.

2. EXPERIMENTAL RESEARCHES

The aim of experimental researches was to investigate the successive (through a larger number of dies simultaneously), i.e. multistage drawing (several times through one die). Multistage drawing implied the performance of investigation several times on one and the same test piece. The specified research is interesting from the aspect that the material always goes into the following drawing stage with changed topography, which influences the process itself (ironing force, friction coefficient etc).

This experiment does not completely imitate ironing through a larger number of dies simultaneously (distance between does is not taken into account, the total ironing force has somewhat different alteration process, since in one part of the process drawing is performed simultaneously through a larger number of dies), but at any rate, the proper conclusions can be made, especially regarding the topography of contact surfaces.

For experimental researches in this paper, two materials were chosen: classic low carbon steel sheet metal C0148P3 and Al-alloy sheet metal, marked with AlMg3 (.43). (Mark according to DIN: AlMg3 F24). In this way, two very different and very modern materials in contemporary industry were included. The mechanical properties of the investigated materials are given in Table 1.

Table 1: Mechanical properties of investigated materials

Material	Angle, °	R_p, MPa	R_m, MPa	R_p/R_m, -	A, %	n, -	r, -	E, MPa
Č0148P3	0°	186.2	283.4	0.657	37.3	0.21860	1.31915	1.957×10^5
AlMg3	0°	201.1	251.0	0.801	12.0	0.13545	0.40510	$0,701\times10^5$

Contact pairs (“die” and “punch”) are made of alloyed tool steel (TS) with great toughness and hardness, marked with Č4750 (DIN 17006: X165CrMoV12). This steel is wear resistant and is foreseen for cold work. Before mechanical forming by abrading, calcinations in oil and loosening were performed.

With the aim of comparative researches, one set of tools was hard chrome plated (Cr). We should mention that the foundation (base) of the tool was thermally treated alloyed tool steel C4750.

One set of “dies” was made of hard metal (HM) marked with WG30 (DIN 4990:G30). Hard material (α-phase) was wolfram carbide (WC), and the connective material was cobalt (β-phase).

When selecting the lubricant for the experimental researches, it was necessary to pay attention to several factors, such as: kinds of material being investigated (steel, aluminum), different consistency of lubricants (grease, paste, lubricate coatings), various lubricant viscosity, lubricant origin (organic, synthetic, mineral), as well as height of contact pressures which dominate at ironing.

On the basis of aforementioned factors, the selection of lubricants which will be used in experimental researches was performed. Their review, including main properties, is given in Table 2.