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# Influence of change of direction of deformation at ECAP technology on achieved UFG in AlMn1Cu alloy

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Materials

## ABSTRACT

**Purpose:** of this paper is to extend a complex evaluation of aluminium alloy, which requires very often knowledge of behaviour of deformation at the ECAP process and achieved strengthening, intensity of deformation and very fine structure. These factors have influence on the mechanical properties and formability. Presented knowledge expresses very important information for exploitation of this alloy.
**Design/methodology/approach:** The methods determining the dependencies of force on the route during the ECAP process were used. Achieved values were directly plotted on PC.
**Findings:** Conclusions of this work consisted in determination of structure and mechanical properties of this alloy.
**Research limitations/implications:** Achieved hardness and microstructure of this alloy will be determined by new research.
**Practical implications:** The results may be utilized for determination of a relation between structure and properties of the investigated alloy in the process of manufacturing.
**Originality/value:** These results contribute to complex evaluation of properties of the AlMn1Cu alloy, namely in the light of achievement of very fine - grained structures and corresponding mechanical and forming properties. The results of this paper are determined for research workers – in order to increase efficiency of the process of severe plastic deformation.
**Keywords:** Plastic Forming; ECAP process of AlMn1Cu alloy; Structure analysis; Hardness

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## 1. Introduction

Preparation of materials with ultra fine-grained structure (UFG) and even nano-structure with the mean size of grain below 1 µm is one of the highly advanced technologies, which was for last approximately 15 years object of basic and applied research. It is expected that these materials have high strength characteristics, as well as good forming parameters, which exceed the properties of the currently produced classical materials. Their utilisation brings at the same time also an important economic effect [1,3,7]. These materials find their use namely in applications, in which obtaining of high strength will lead to reduction of mass of the given structure, whereas good toughness will contribute to the safety of the structure (steels and alloys of non-ferrous metals in the automotive industry, aluminium and magnesium alloys in the aircraft industry). Some types of ultra fine-grained alloys have already been implemented into mass production, whereas the expected properties are obtained by creation of ultra fine-grained structure and its stabilisation [4,8,10]. At the same time an intensive research of completely new manufacturing technologies is running. It appears that one of the ways for obtaining the ultra fine-grained structure or even nano-structure is use of severe plastic deformation of materials of such magnitude, which cannot be achieved by ordinary methods of forming [5,6,11,14].

The principle of this new concept of the forming tool for development of ultra fine-grained materials will be based on new design of the tool channel. New structural solution makes it possible to achieve much higher amount of deformation by change of the route of deformation at one pass of the tool. This is new approach to designing of the forming tool, which differs from the so far published scientific literature dealing with the issues of manufacture of nano-structural materials [12,15]. It concerns primarily a change of route of deformation at the first pass through the ECAP channel. This results in increase in the amount of deformation leading to higher refining of grain and therefore to overall increase in efficiency of the whole process of severe plastic deformation. Structural modification concerns the horizontal channel, which is deflected by 10° and 20° in respect to the horizontal axis.

A tool with the same geometry as in the case of the tool without deflection of horizontal channel was used (R1 = 4 mm, R2 = 0.5 mm, Ψ = 90˚, Φ = 90˚ and b = 10 mm). At the place of connection between the horizontal and vertical channels a rounding R3 = 5 mm was applied and the bottom channel of the tool was deflected by 20° and slightly expanded in its output part (see Fig. 1) [2].

## 2. Proposed new geometry of the ECAP dies

A die with the same geometry as in the case of the tool without deflection of horizontal channel was used (R1 = 4 mm, R2 = 0.5 mm, Ψ = 90˚, Φ = 90˚ and b = 10 mm) [2]. At the place of connection between the horizontal and vertical channels a rounding R3 = 5 mm was applied and the bottom channel of the tool was deflected by 20° and slightly expanded in its output part. New ECAP dies we observe in the Figure 1.

The paper should begin with the introduction in which the state-of-the-art of the issue concerning the paper will be presented generally and concisely. It is necessary to quote references taking into consideration the remarks included in the section “References”. It is necessary to present the aim of works included in the paper and clearly emphasise the originality of solutions and content-related approach to the issue worked out and described by authors. Exemplary section headings and range of the subsequent sections of the paper are given roughly which we wish you to adopt during the preparation of your paper.

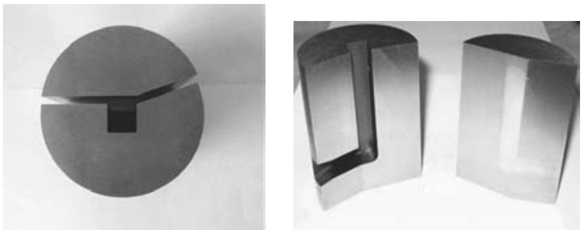


Fig. 1. New geometry of the ECAP dies (axis offset 20°)

### 2.1. Tested material - alloy AlMn1Cu

The material has higher strength than pure aluminium and it preserves high formability. It has good resistance to chemical agents as well as to corrosion. It is very well weldable by all welding methods. It is used in a soft state or in a state after cold forming [9,13]. The material finds its use particularly in products with lower loads that were prepared by deep drawing, bending and welding. Table 1 gives its chemical composition.

Table 1.
Chemical composition of the alloy AlMn1Cu

| Element | Si | Fe | Cu | Mn | Other | Al |
|---|---|---|---|---|---|---|
| [%] | 0.55 | 0.4 | 0.15 | 1.1 | 0.15 | rest |

The working site for development of new technologies has at its disposal a hydraulic press of the type DP 1600 kN. Control system of the press is equipped with servo-operated valve enabling continuous setting of change of the piston speed, i.e. also change of the mean strain rate. Control can be effected manually or by a program. The program enables setting of the necessary lift of the tool and assignment of the corresponding speed to it.

## 3. Experimental determination of basic forming parameters for obtaining the necessary structural and mechanical properties

The ECAP forming was realised under the following conditions:

- extrusion at 22 °C – channel deflection 0°
- extrusion at 22 °C – channel deflection 10°
- extrusion at 22 °C – channel deflection 20°

In all the series of samples total number of 5 to 6 passes was applied in dependence of the development of extrusion [3]. The extruded material was then divided into individual series for manufacture of individual testing specimens for metallographical evaluation and mechanical tests in combination 1$^{st}$, 4$^{th}$, 5$^{th}$ pass. Obtained results are shown in the Figure 2.

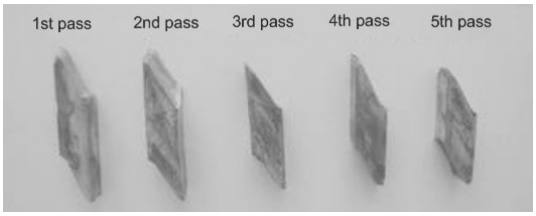



Fig. 2. Shape of specimen after single extrusion

Altogether 15 specimens in initial state were prepared for individual passes through the ECAP tool – both for classical channel with no deflection and then also for deflections of 10° and 20°. Examples show the courses of strengthening at the lift for individual passes of the given alloy. The graph shows the influence of the number of passes on strengthening of the given alloy.

In the next part of experimental works the obtained strengthening at individual passes through various designs of the ECAP channel was compared [2].

**Classical design of the ECAP technology**

Obtained results the curve of strengthening are show in the Figure 3.

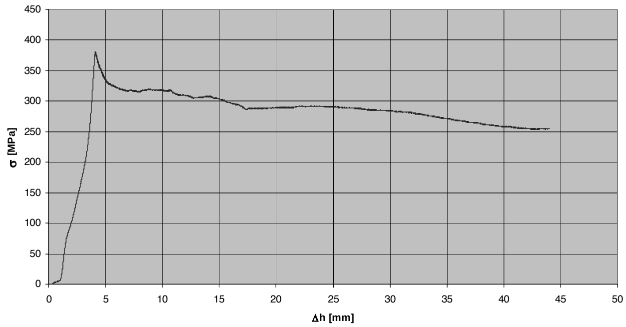



Fig. 3. Courses of dependencies of the strengthening on the route, deflection 0°

**Influence of the number of passes on the magnitude of the strengthening at various designs of the ECAP tool**

Influence of channel deflection on the strengthening after single passages through ECAP die is show in the Figures 4-6.

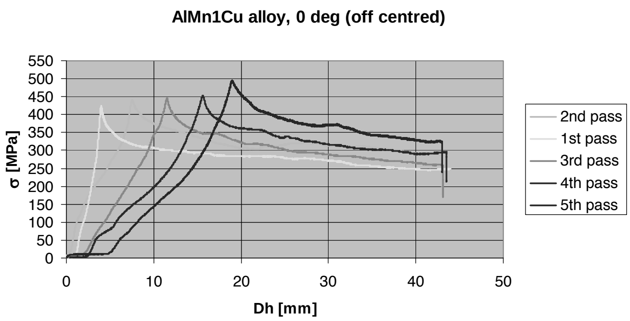



Fig. 4. Channel deflection 0°

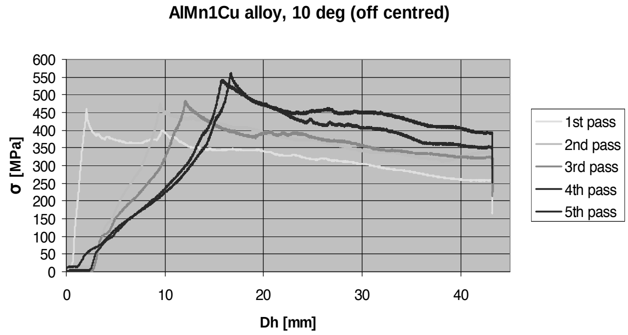



Fig. 5. Channel deflection 10°

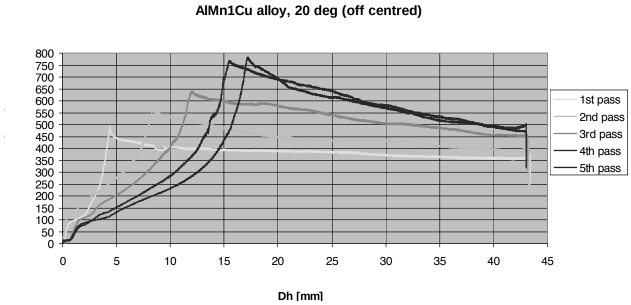



Fig. 6. Channel deflection 20°

**Influence of the change of design of the ECAP tool (deflection) on the magnitude of the strengthening**

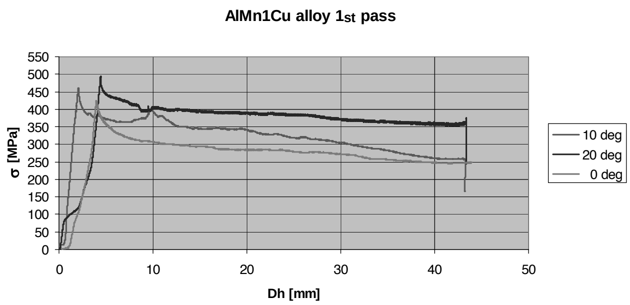



Fig. 7. Influence of the channel deflection on strengthening, first pass

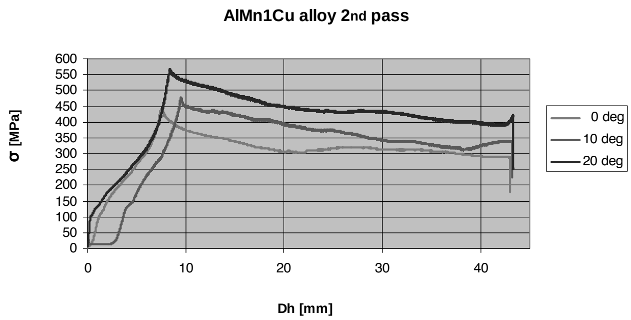



Fig. 8. Influence of the channel deflection on strengthening, second pass

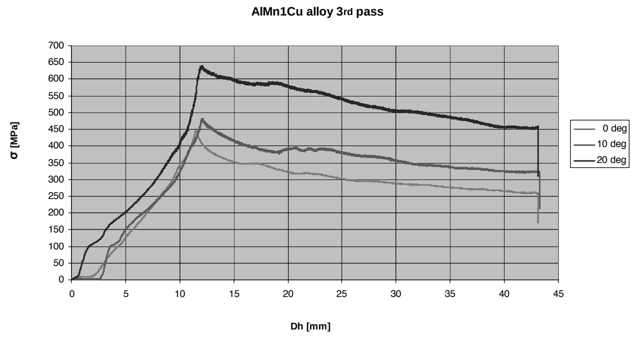



Fig. 9. Influence of the channel deflection on strengthening, third pass

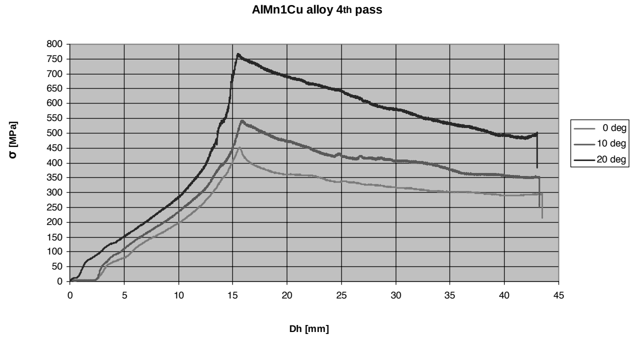



Fig. 10. Influence of the channel deflection on strengthening, forth pass

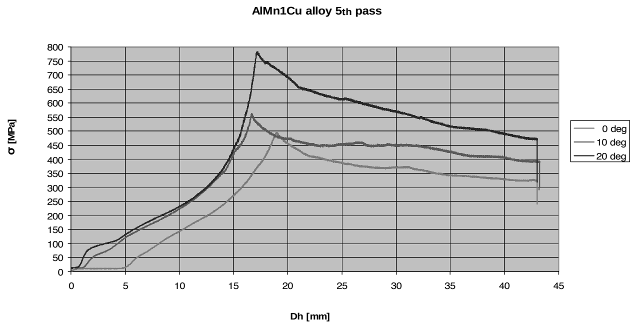



Fig. 11. Influence of the channel deflection on strengthening, fifth pass

## 4. Summary of findings at ECAP process

The obtained results proved unequivocally big influence of the change in design of the ECAP tool on the increase of resistance to deformation and therefore also on strengthening of the given alloy at individual passes. Obtained results we observe in the Figures 7-11. Table 2 gives maximum of strengthening at different deflection. Table 3 gives maximum of intensity of deformation.

Table 2.
Maximum of strengthening (MPa) obtained at individual passes ($3^{rd}$-$5^{th}$) through the ECAP tools of different designs (different deflection of the channel horizontal part)

| Deflection/ Pass No. | $3^{rd}$ pass | $4^{th}$ pass | $5^{th}$ pass |
|---|---|---|---|
| 0° | 456 | 464 | 505 |
| 10° | 470 | 545 | 570 |
| 20° | 500 | 770 | 795 |

Increase of the strengthening in case of the channel deflection by 20° in the $1^{st}$ and the $2^{nd}$ pass is very important finding, which gives us a pre-requisite for obtaining even higher amount of deformation and thus also ~~of~~ substantial increase of efficiency of the ECAP process [2]. This assumption was confirmed by mathematical simulation. The results will be verified by mechanical tests and metallographical analysis.

Table 3.
Influence of the channel geometry on the obtained magnitude of intensity of deformation at individual passes through the ECAP die

| Deflection / passes | $1^{st}$ | $2^{nd}$ | $3^{rd}$ | $4^{th}$ | $5^{th}$ |
|---|---|---|---|---|---|
| 0° | 1.05 | 2.05 | 2.75 | 3.5 | 4.2 |
| 10° | 1.1 | 2.15 | 2.95 | 3.85 | 4.4 |
| 20° | 1.15 | 2.3 | 3.3 | 4.3 | 5.1 |

The influence of the changed design of the ECAP tool was unequivocally confirmed. The route of deformation is changed and it therefore brings about substantial increase of the deformation intensity, namely at the $4^{th}$ and $5^{th}$ passes through the tool. Process of multiple plastic deformations is thus much more efficient.

## 5. Metallographic evaluation

Metallographic evaluation was made with use of the light microscopy and TEM technology.

For metallographic analyses a series of samples after passes were prepared. After usual metallographic preparation the samples were electrolytically etched.

Microstructure of the used alloys in initial state is shown in Figure 12.

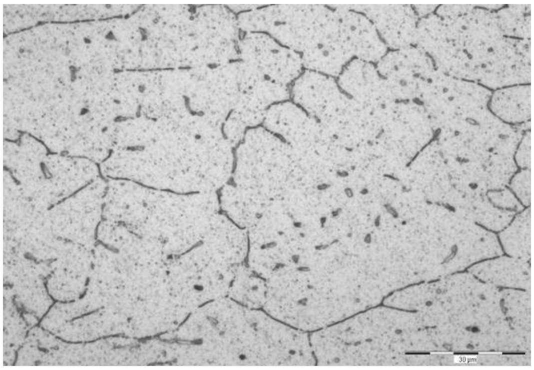


Fig. 12. AlMn1Cu microstructure - initial state

Microstructure of the samples after ECAP processing is shown in Figures 13-22 (Figures 13-17 show surface parallel with direction of passing, Figures 18-22 perpendicular to direction of passing).

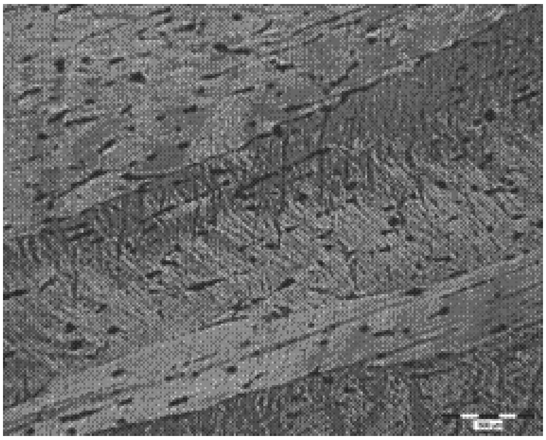


Fig. 13. AlMn1Cu microstructure after the 1st pass (deflection 10°)

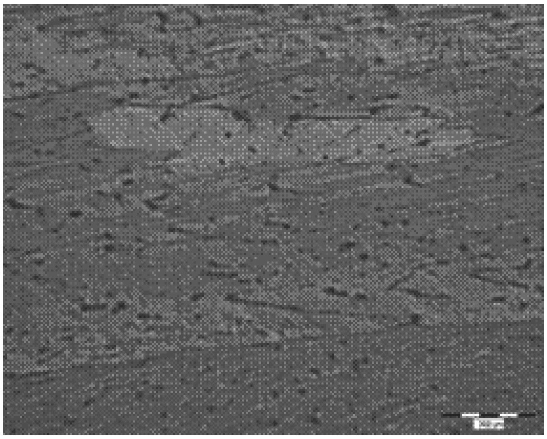


Fig. 14. AlMn1Cu microstructure after the 2nd pass (deflection 10°)

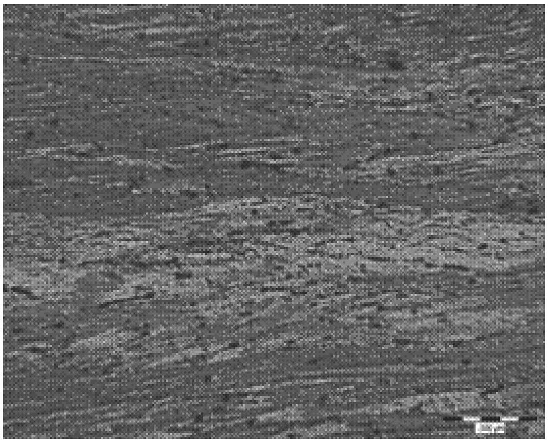


Fig. 15. AlMn1Cu microstructure after the 3rd pass, (deflection 10°)

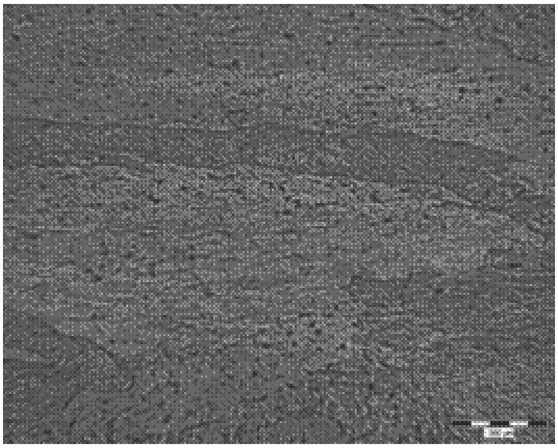


Fig. 16. AlMn1Cu microstructure after the 4th pass (deflection 10°)

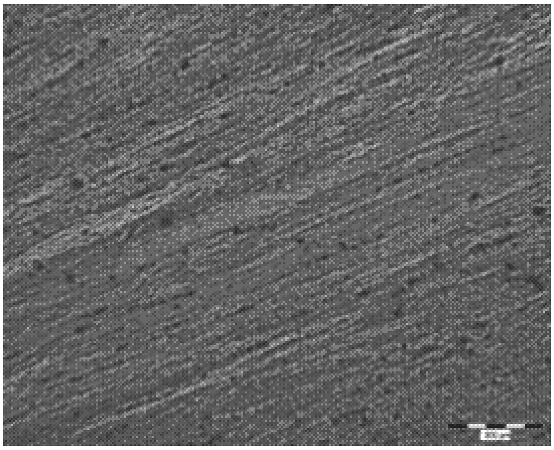


Fig. 17. AlMn1Cu microstructure after the 5th pass (deflection 10°)

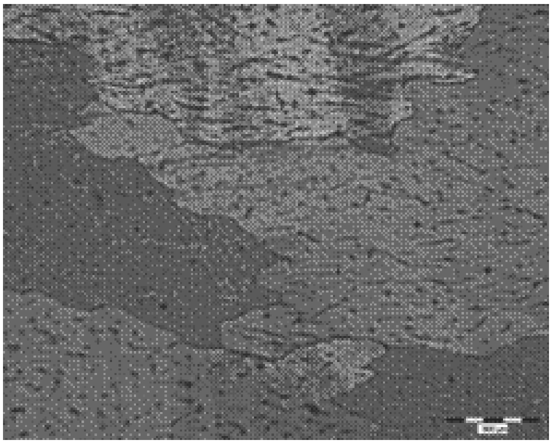


Fig. 18. AlMn1Cu microstructure after the 1st pass, (deflection 10°) - perpendicular

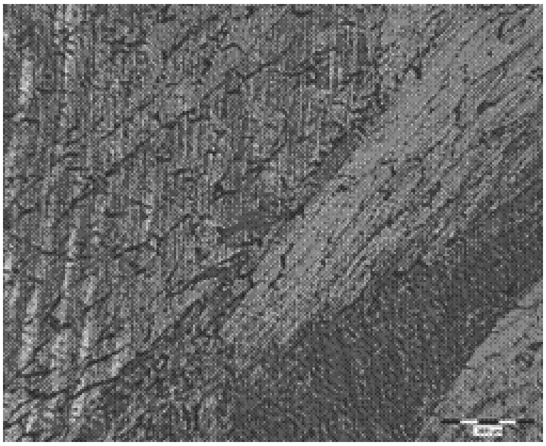


Fig. 19. AlMn1Cu microstructure after the 2nd pass, (deflection 10°) - perpendicular

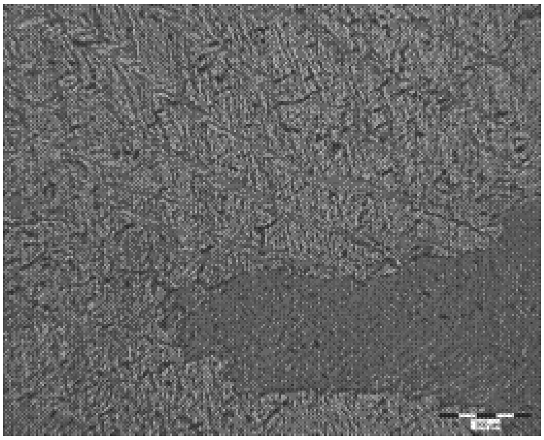


Fig. 20. AlMn1Cu microstructure after the 3rd pass, (deflection 10°) - perpendicular

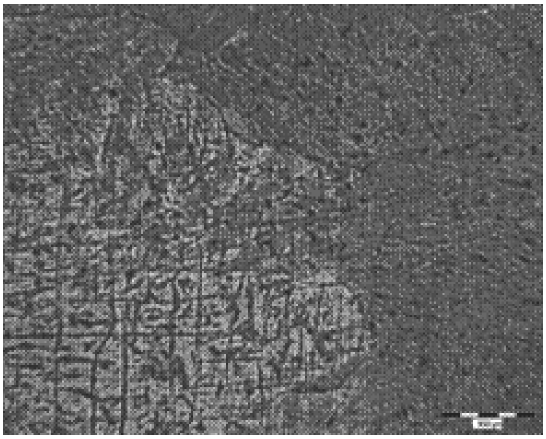


Fig. 21. AlMn1Cu microstructure after the 4th pass, (deflection 10°) - perpendicular

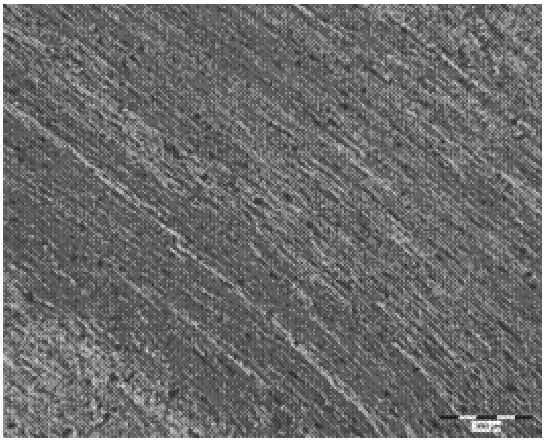
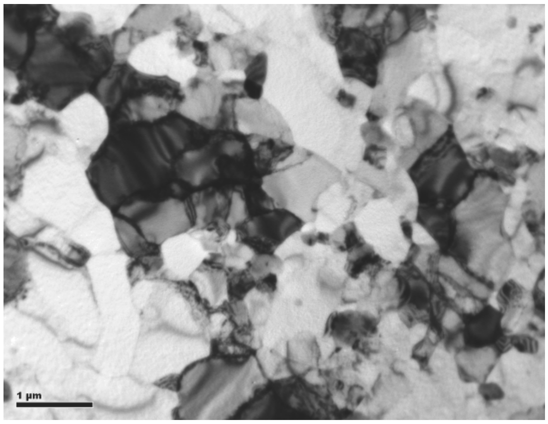


Fig. 22. AlMn1Cu microstructure after the 5th pass, (deflection 10°) – perpendicular

a)




b)

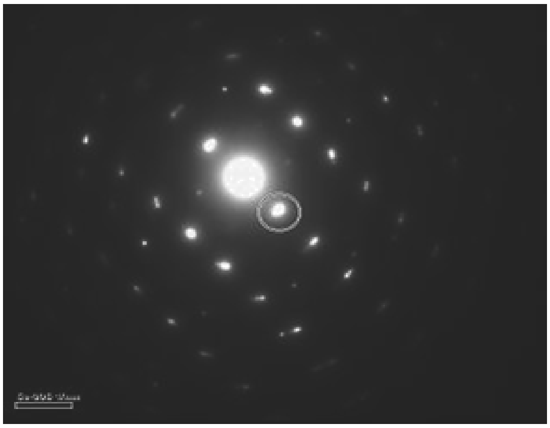


Fig. 23. EM of AlMn1Cu after the 1st pass (deflection 10°); a) view of TEM, b) diffraction pattern

Next metallographic evaluation was made with use of the TEM technology. A series of metallographical evaluations was realised in collaboration with the branch of the Polish Academy of

Sciences in Cracow. Series of pictures of samples after selected passes are shown in Figures 23, 24. The obtained results appear to be highly interesting. The occurrence of the grains in the alloy AlMn1Cu with the mean grain size of approx. 1µm to 2µm was confirmed, as well as great number of dislocations inside the grains already after the first pass. Investigation of the alloy after the fifth pass shows fine-grained structure with the mean grain size 0.2 µm to 0.5 µm, as well as high disorientation between the grains. In this alloy a process of dynamic re-crystallisation was probably observed in smaller extent.

a)

b)

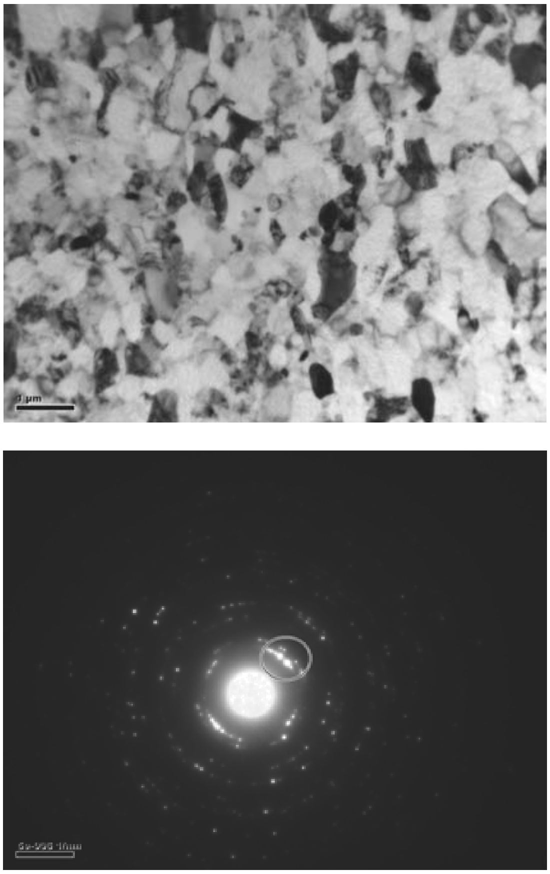


Fig. 24. EM of AlMn1Cu after the 5th pass (deflection 10°); a) view of TEM, b) diffraction pattern

## 6. Hardness measurements

Hardness on the surface of metallographic samples perpendicular to direction of passing (1 - 5) is shown in Figure 25.

### 6.1. Obtained results

The measurement was performed on the transverse cross-section of the sample. The values measured at individual passes have been averaged along the sample width (10 mm).

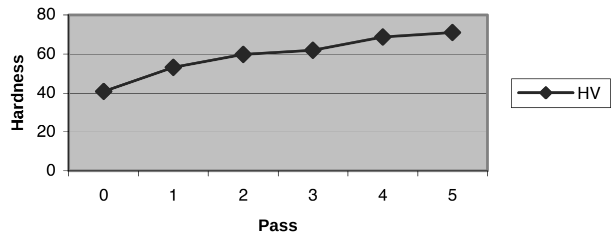



Fig. 25. Hardness of AlMn1Cu after the 5 passes (deflection 20°)

It is obvious from the achieved results of measurement of hardness after individual passes, that it is almost doubled in comparison with its initial state (hardness in initial state - 40 HV, hardness after the 5th pass - 78 HV).

## 7. Conclusions

It is obvious from the obtained results that new design of geometry of the extrusion channel brings higher efficiency of the ECAP process. Positive influence of the change of route of deformation on increase of magnitude of strengthening and also intensity of deformation was unequivocally proven. Deflection of the tool channel in its horizontal part leads to substantial increase in efficiency of the ECAP technology using multiple plastic deformation. Intensity of deformation at the 5th pass in classical channel $\varepsilon = 4.2$, in the channel with modified geometry $\varepsilon = 5.1$. Positive impact on resistance to deformation was unequivocally proved and metallographical evaluations have also confirmed more intensive refining of grains already after the first pass.

## Acknowledgements

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