# Plastic instabilities during processing of AlMg alloy

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# PLASTIC INSTABILITIES DURING PROCESSING OF AlMg ALLOY

## ABSTRACT

During the plastic deformation of most metallic materials, the normal material flow takes place in part of the material, which we call deformation zone. There are some exceptions in certain alloys where process of plastic deformation is unstable and there is inhomogeneous plastic flow at certain parameters of plastic processing. Examples of such instabilities are the inhomogeneous plastic deformations such as Lűders bands and the Portevin-Le Chatelier effect, which appear in the form of deformation bands. Instabilities like these cause problems during metal processing into final products. The focus of this research was to determining the type of instability in received AlMg alloy. Visualization of material flow, displacement and deformation measurement during the static tensile test was performed using the DIC method. From results of tensile tests, repetitive serrations on the stress-strain curve during plastic deformation were observed. DIC analysis showed inhomogeneous deformation during the test, which lead to reasonable assumption that the observed instability was Portevin-Le Chatelier effect. To investigate the mechanisms of deformation, microstructures were recorded on samples before, during and after propagation by PLC band. Structural analysis showed that the deformation takes place through the movement of dislocations, which is indicated by their increased density at the PLC front and behind front after it passes.

**Keywords:** plastic instabilities, AlMg alloy, Portevin Le Chatelier effect, Digital Image Correlation

## 1. Introduction

The ability of metals and their alloys to be shaped by plastic deformation, and to improve their mechanical and physical properties, is the reason for their wide application in daily life. During plastic deformation of most metallic materials, normal flow of the material takes place in the deformation zone. Plastic deformation is observed as uniform flow of the material, which is manifested as uniform hardening on the stress-strain diagram. There are some exceptions in certain alloys that are considered important technical materials. In these cases, the process of plastic deformation is unstable and there is inhomogeneous plastic flow under certain deformation conditions [1]. In this cases, various phenomena's occur that are subject of many researches. Examples of such phenomena are Lűders bands [2] and the Portevin-Le Chatelier effect, where instabilities manifest as localized deformation in the form of deformation bands [3]. The Portevin – Le Chatelier effect, also known as the PLC effect, occurs in various alloys with different crystal lattices in materials of great industrial importance, e.g. in some types of steel TRIP and TWIP steels [4] and some aluminum alloys [5]. The PLC effect leads to issues related to visual and structural changes. On the surfaces of products made of aluminium alloys in which the PLC effect occurs during the deformation process, rough and undesirable marks may appear. Surface changes represent initial cracks and stress concentrators during the further processing of such materials and they can potentially lead to failure due to material fatigue [6]. Furthermore, the occurrence of the PLC effect in materials leads to an increase in stress, hardness, tensile strength and strain hardening rate, while on the other hand it decreases the ductility, toughness and strain rate sensitivity [7].

Since the PLC effect occurs in wide range of aluminium alloys, these alloys are often used as material for the study of the PLC effect, primarily AlMg alloys [8]. Tensile tests are most used for determining the occurrence of PLC effects on certain alloys [9]. At a certain range of strain rate and temperatures, destabilization of the plastic flow may occur, which manifests itself on the stress/strain curve as serrations and localized deformation bands moving through the gauge length of the specimen throughout the duration of the plastic deformation [10]. There are three main types of deformation lines, A, B and C type, whose appearance depends on the strain rate and temperature [11]. There are also rare types of E and D lines mentioned in some literature [12]. At higher strain rates and lower temperatures type A bands appear, at medium strain rates and temperatures, type B bands appear and finally at low strain rates and high temperatures type C bands appear [13]. In most research, the visualization and properties of PLC bands are investigated using thermography and Digital Image Correlation (DIC) methods parallel with tensile test [14].

The generally accepted mechanism of the PLC effect at the microscopic level is the Cottrell model, which is based on the interaction between mobile dislocations and the atoms of the dissolved elements in the alloy [15]. This model is also known as dynamic strain aging (DSA) of the material [16]. In the case when the concentration of dissolved atoms around the dislocations becomes sufficient, the movement of the dislocations is blocked, which leads to a decrease in number of mobile dislocations and an increase in stress. When the stress reaches the value at which the blocked dislocations are released or multiply, the number of mobile dislocations increases, which leads to the stress decrease. The repetitive increase and decrease of stress leads to a discontinuity on the strain hardening line, which corresponds to the phenomenon of deformation aging [13]. According to the DSA theory, the strain rate sensitivity of flow stress becomes negative (nSRS) in a certain temperature and strain rate range, and unstable plastic flow is observed under these conditions.

Many factors influence the occurrence of the PLC effect, such as the concentration of solutes and the composition of the alloy [17,18]. The density of dislocations and grain size are also significant in the occurrence of the effect [11], but all the mentioned factors do not necessarily have a significant influence. Although the addition of elements to the alloy attempts to improve the mechanical properties of the alloy, the composition of the alloy unfortunately has an influence on the appearance of the effect or nSRS. In AlMg alloys, for example, the phenomenon can be observed as a function of the Mg content, according to [19], by increasing the Mg content, both DSA and the occurrence of nSRS increase, leading to a strengthening of the PLC effect.

The commercial AlMg alloy 5754 is a very commonly used alloy, intended for further cold working by plastic deformation. As it belongs to the group of alloys with a very common occurrence of plastic instabilities, research was carried out to determine whether there is plastic instability during the cold deformation of this alloy, and if their presence is established, which instability is involved.

## 2. Experimental procedures

Tensile tests were carried out to investigate is there any kind of plastic instabilities during deformation of commercial 5754 AlMg alloy. Specimens were taken from cold-rolled sheet from 5754 Al alloy in the rolling direction. The specimens were cut out and prepared for the mechanical tests by on a CNC machine. The dimensions of the specimens gauge length was 50 mm × 20 mm × 3 mm. For the DIC method specimens were properly prepared by applying white matt coating on the surface and then black spackles were randomly sprayed on the specimens surface, Fig. 1.

Fig. 1. Prepared specimen

Tensile test was performed on Hegewald&Peschke 100kN tensile machine at constant displacement of 20 min/min at room temperature. Paralel with tensile testing Digital Image Correlation (DIC) methode was performed, using ARAMIS Adjustable 2D/3D camera system, Fig. 2.

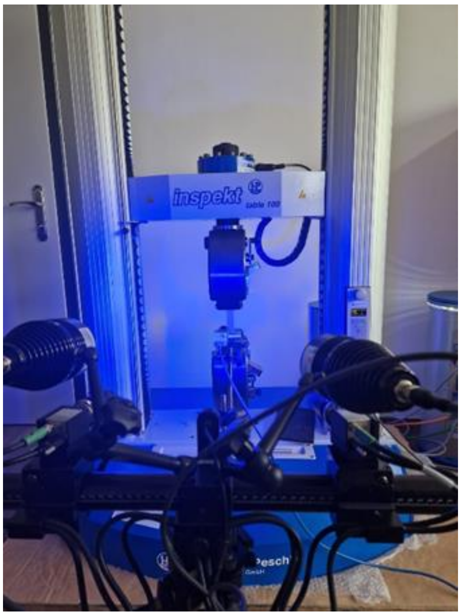



Fig. 2. ARAMIS Adjustable 2D/3D camera system

Visualization of the material flow, measurement of displacement and deformation during the experiment were determined by analysis of DIC recordings in the correlation programme GOM correlate PRO.

For metallographic analysis samples were prepared by grinding and polishing (gradations 120, 240, 400, 600, 800, aqueous solutions of $Al_2O_3$ respectively). Etching of the samples was carried out with Poulton solution (12 ml konc. HCl + 6 ml HNO3 + 1 ml HF (48 %) + 1 ml $H_2O$). Metallography was recorded with an Olympus GX51 light microscope equipped with a DP70 digital camera, and with the AnalySIS Materials Research Lab software package.

## 3. Results and discussion

A representative stress-time diagram of tested alloy is shown in Fig. 3.

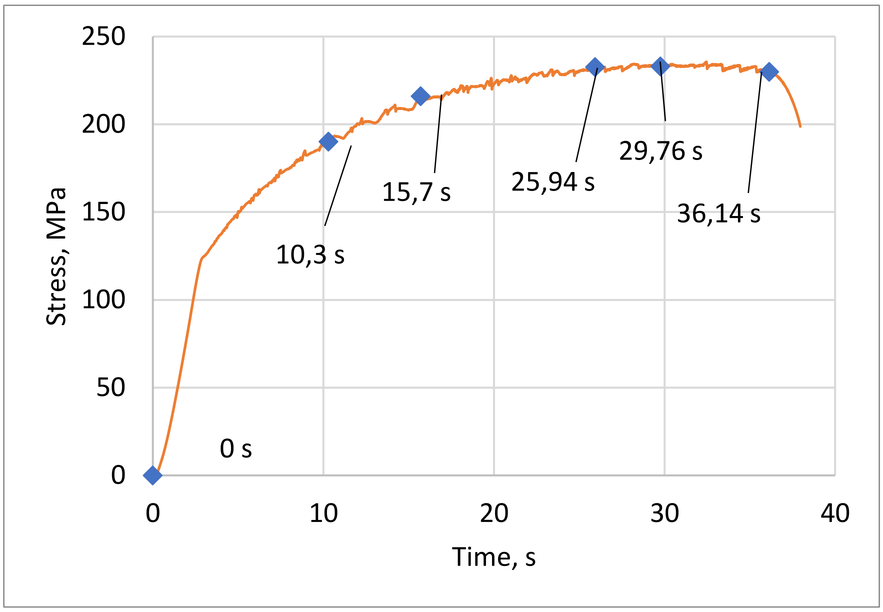



Fig. 3. Stress-time diagram

During the tensile test it was noted the presence of serrations on the stress curves, Fig.3. On the Fig. 3, curve shows the times at which the deformation maps were recorded with DIC methode (Fig. 4).

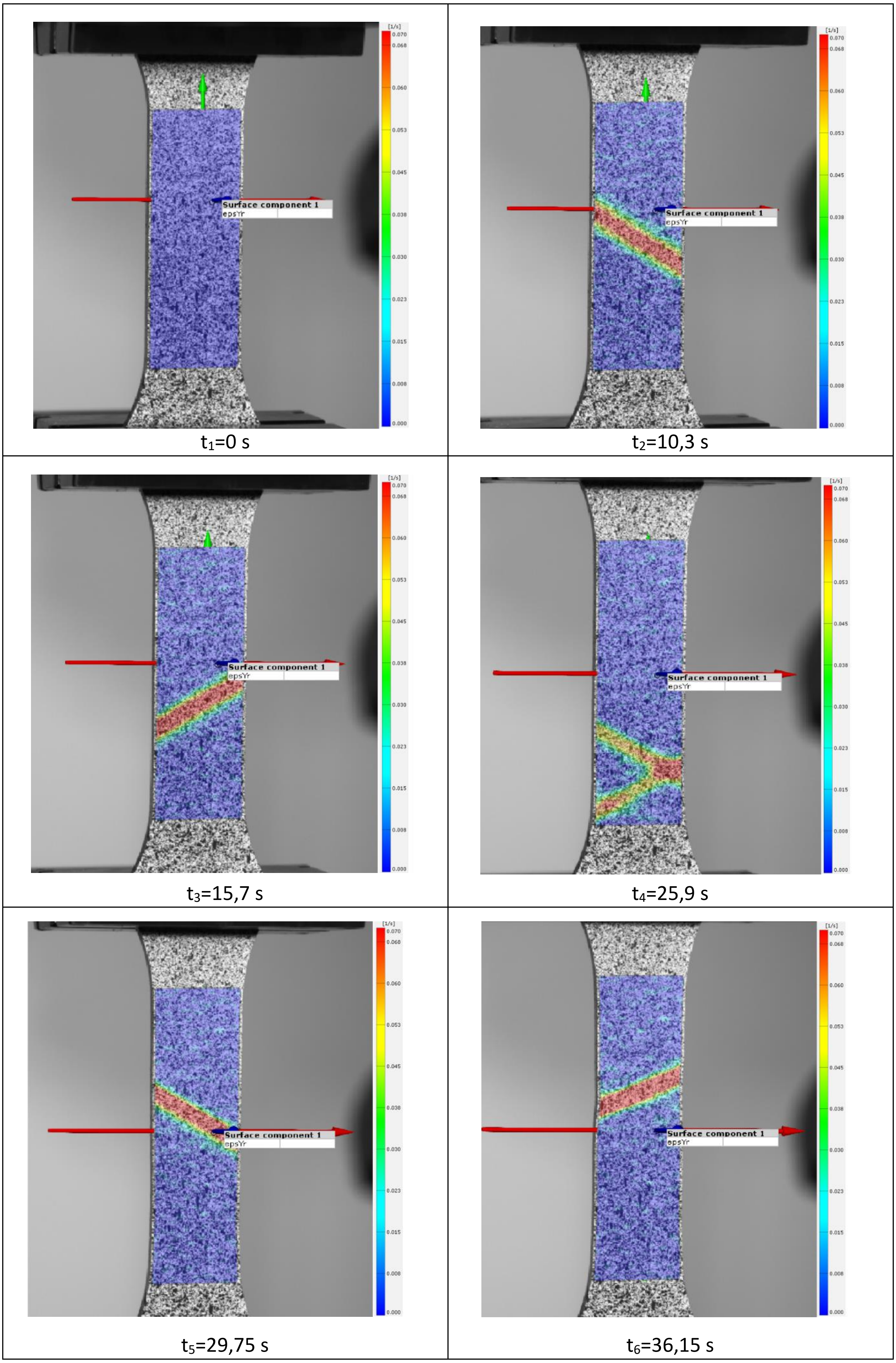



Fig. 4. DIC representation of the formation and propagation of multiple lines

During the tensile testing, DIC method shows that deformation occurs in form of narrow bands (lines), Fig. 4. These lines propagate in different directions through the specimen. At certain periods, several lines form at the same time and may cross each other, which usually happens right before the specimen failure.
It is clear from Fig. 3. and Fig. 4. that the observed plastic instabilities are indeed a consequence of the occurrence of the Portevin – Le Chatelier (PLC) effect in this alloy. This is evident from the serrations of the stress curve and the deformation maps recorded by DIC analysis.

Consequently, to observe the structural changes that PLC effect does on the material, microstructural analysis was carried out. Deformation of specimens was stopped at a certain points, right at the moment that first line propagated the half way through gauge length of specimen, Fig. 5.

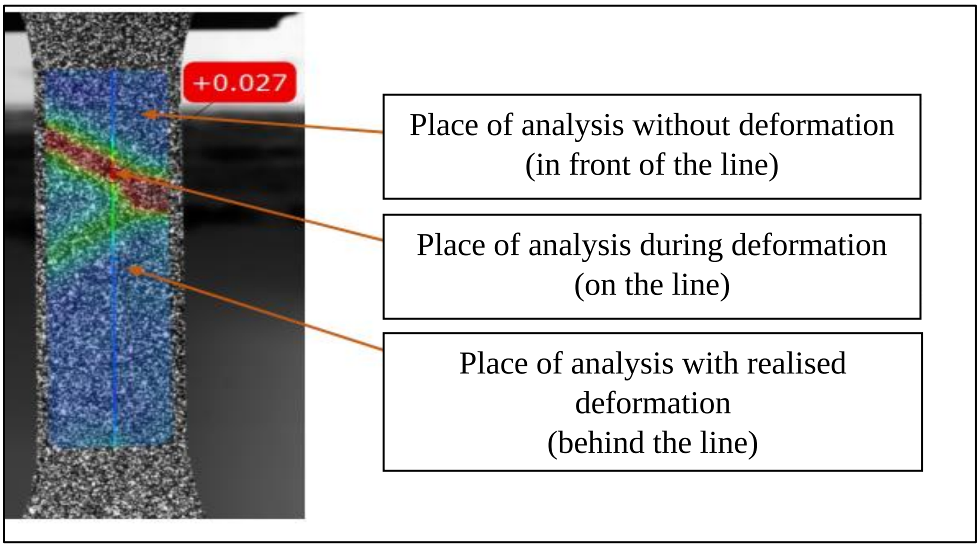
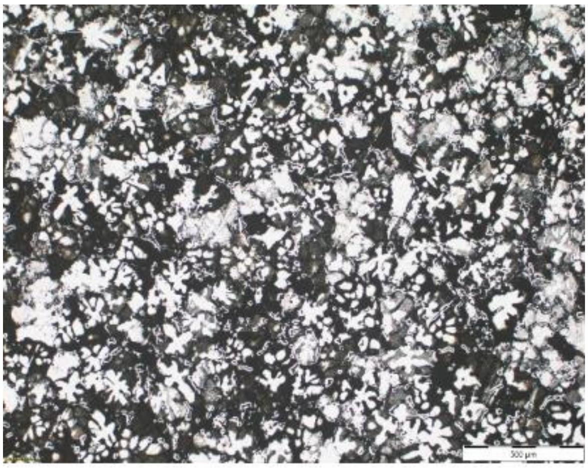
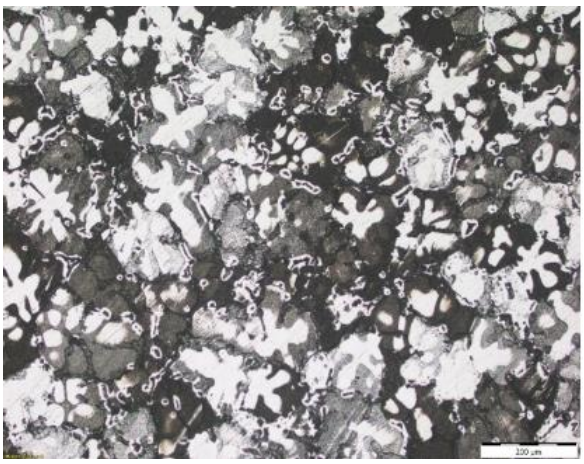



Fig. 5. Points of structural analysis

Microstructure was firstly observed before the PLC band deformed specimen, where the initial microstructure of the AlMg alloy is shown, Fig. 6. (a),(b).



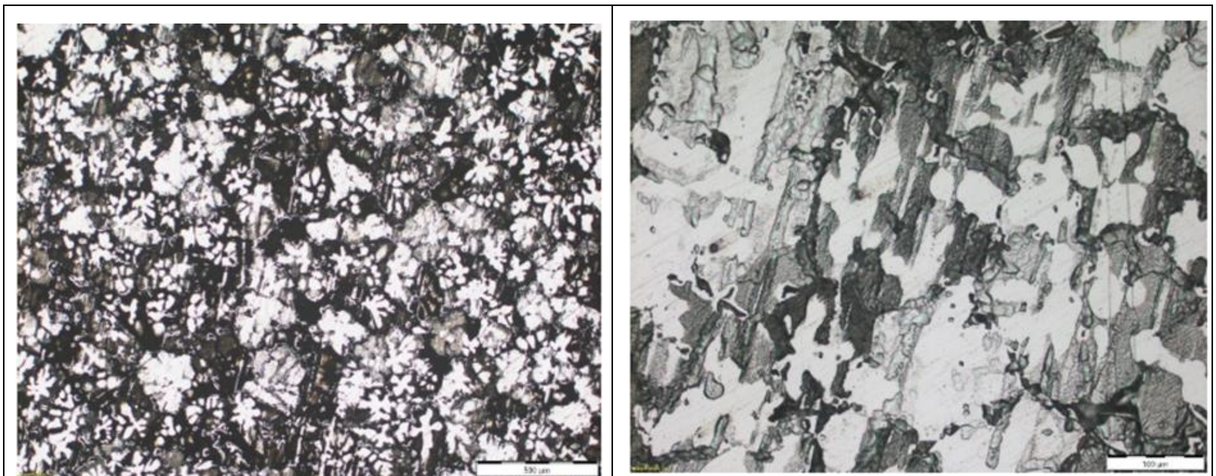
a)



b)

Fig. 6. The initial microstructure of the AlMg alloy at a magnifications a) 50x, b) 100x

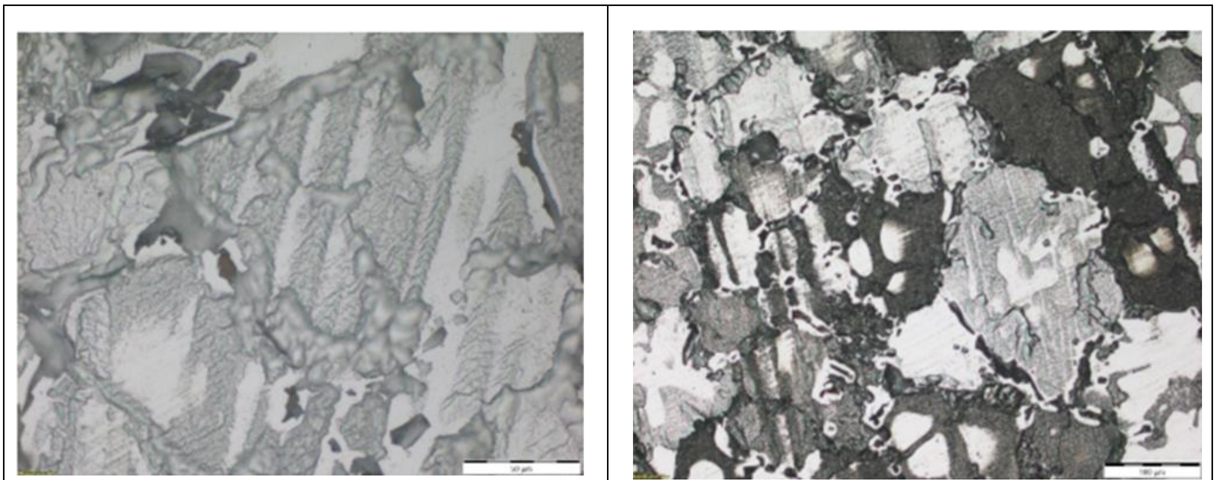
Then the microstructure was observed on the PLC band front, where deformation occurred, where the influence of deformation of PLC band on the microstructure of the alloy is visible, Fig.7. (a), (b).



a) b)

Fig. 7. Microstructure of the AlMg alloy on the PLC line at a magnifications a) 50x, b) 200x

The last image was taken behind the PLC line, where at higher magnifications the structure after the line propagation and the influence of the line on the structure can be seen more clearly.



a) b)

Fig. 8. Microstructure of AlMg alloy after passing through the PLC line at a magnifications a) 500x, b) 200x

In Fig. 6. (a), (b) the initial microstructure shows a characteristic structure of AlMg alloy with differently oriented grains. The microstructure on the PLC line, Fig. 7 (a), (b), shows deformed grains and clearly visible slip lines, from which it can be concluded that the mechanism by which the deformation in PLC line takes place is translational slipping. Figure 8 (a), (b) shows the microstructure after the propagation of the PLC line and it is visible that the PLC line leaves behind a deformed state similar to that of the PLC line itself. At higher magnification, dislocations are visible that were not observed in the undeformed area of the sample specimen.

## 4. Conclusions

The results of the static tensile test show that AlMg alloy is an alloy with a tensile strength of 230-235 MPa. Instabilities, in a form of serrations of stress curve, during the static tensile test are clearly visible. The plastic instabilities are a consequence of the occurrence of the Portevin – Le Chatelier effect (PLC) in this alloy. This is evident from the serrations of the stress curve and the deformation maps recorded by DIC analysis.

The results of the microstructures analysis show that the PLC effect causes certain microstructural changes compared to the initial microstructure and that the deformation process takes place by mechanism of translational slipping. Comparing the microstructure on the PLC line itself and the microstructure after passing through the PLC line, no significant difference can be seen.

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