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Research of Mechanical Properties of the Aluminium Alloy Amag 6000 under the Plane Stress State Conditions

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Today's demands directly encourage to utilize the light alloy materials in industrial production. In the automotive industry, there is an increasing tendency to reduce the total weight of the car and thus also the weight of the individual car-body parts. A correct description of the material deformation behaviour with respect to the different stress states is very necessary for the own possibility to use these materials in the production. This paper describes a measurement of the mechanical properties and deformation behaviour of aluminium alloy Amag 6000 under the plane strain conditions. Thus these properties are monitored and evaluated by means of the plain strain tensile test. In this case, the plane strain is achieved by the shape concept of the testing specimen, which is loaded by the uniaxial tensile stress state using a standard testing device. The determined mechanical properties and the resulting stress-strain curves of the material under the plain stress state can be further used at defining material models for a more accurate description of the material deformation process during the sheet metal forming process.

Keywords: Aluminium, Aluminium Alloys, Sheet Metal Forming, Plane Stress State, Plane Strain Tensile Test, Mechanical Properties

1 Introduction

Materials based on the light alloys belong nowadays among the most sought-after and attractive materials, when the actual tendency, especially in the automotive industry, is to reduce the specific weight of the manufactured parts. Aluminium in its metallic form has been known since 1825, when it was firstly isolated by the Danish physicist H.Ch. Oested, but its processing on an industrial scale did not occur until the turn of the 19th and 20th centuries [1, 2]. The great boom in the utilization of aluminium and its alloys was undoubtedly due to the great development of the automotive industry at the end of the 20th century, where aluminium alloys are widely used not only for the production of various car-body parts [1, 2]. In general, aluminium alloys are sought after and demanded as a structural material because of their low specific weight. The density of pure aluminium is equal to 2.69 g/cm^3. However, the advantage of low weight is accompanied by the disadvantage of low modulus of elasticity compared to steel (about 69 GPa versus 210 GPa). This has to be compensated for example by the higher thickness of the given component, so that the full potential of the low weight cannot be fully exploited. However, aluminium and its alloys offer an advantageous combination of not only mechanical properties, but also physical, chemical or technological properties. Thus, in addition to low weight, the main advantages include corrosion resistance, thermal and electrical conductivity or recyclability. On the other hand, the main disadvantages of aluminium alloys (besides the low modulus of elasticity) rest e.g. in their lower formability than steel, poor weldability or the high costs associated with their processing [2–5].

The processing of aluminium and its alloys, not only in the automotive industry, is primarily associated with an accurate description of deformation during the production process of a given component. In order to describe the deformation process correctly, as accurately as it is possible and to predict the individual processes during the component production, it is necessary to properly define material models that can be used to describe such deformation process. For example, in the environment of production process mathematical modelling by means of the numerical simulations. With respect to the facts mentioned above, the experimental part of this paper deals with the investigation of the deformation behaviour of the aluminium alloy Amag 6000 under plane strain conditions. The description and conditions of mechanical testing, the course of test and resulting characteristics of the material respecting the given loading method (plane strain test) are described in the following sections [5–7].

2 Plane strain tensile test

One of the important aspects to correctly describe the deformation behaviour of material rests in the correct and accurate definition of the tested material yield criterion. Advanced material models that consider material anisotropy and include a more accurate description of the elastic-plastic transition behaviour require higher amount of the input material data and characteristics that define this moment in some way and take into account the individual stress states within the formed material. The plane strain test is one of the material tests that help to increase accuracy of this boundary at the moment of the yielding (transitions from elastic to plastic region) – thus so-called yield criteria. The plane strain test simulates a plane strain condition and by performing this test is possible to obtain a hardening curve under the given loading method. The importance of this test, which influences the used yield criterion through the so-called hinge-point, is shown in Figure 1 [8, 9].

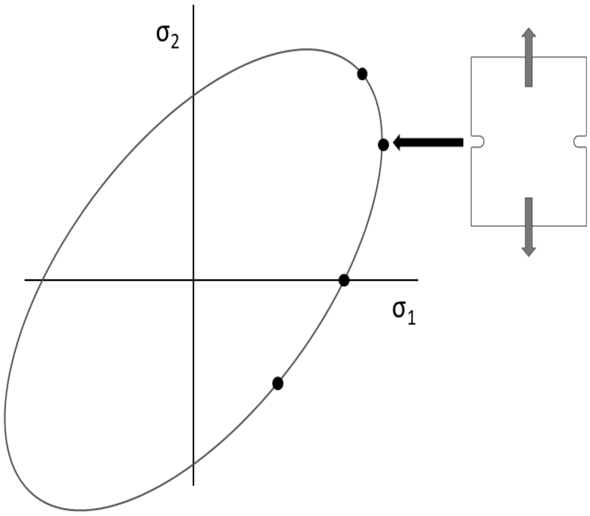


Fig. 1 *Importance of the Plane Strain Test for the yield criterion definition*

To perform the plane strain test, it was first necessary to manufacture the testing specimens regarding the selected material rolling directions - 0°, 45° and 90°. Testing specimens were prepared in a defined shape that follows and guarantee the conditions for the creation of the plane stress state - i.e. shape and dimensional design of the testing specimen must ensure that the deformation in the specimen width direction equals zero. The shape concept of the testing specimen can be seen in Figure 2. Production of these testing specimens was carried out by EDM wire cutting and then areas, where the strain is monitored, were machined using grinding. All of that was done to prevent the early failure of the specimen during the test before its plasticity is exhausted. The initial monitored dimensions of the testing specimens with respect to the individual rolling directions were as follows: width B_0 = 60 mm = *const.*, thickness T_0 = 1 mm and measured length L_0 = 10 mm.

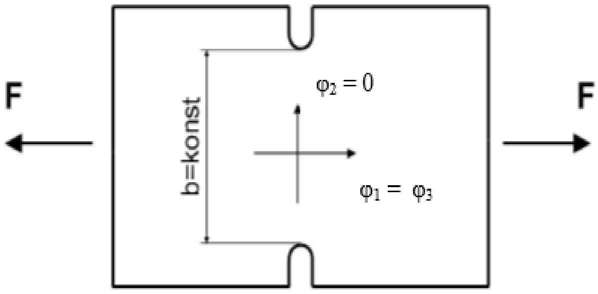


Fig. 2 *Testing specimen for the Plane Strain Tensile Test*

The whole test was carried out on the testing device TIRATest 2300 as can be seen in Fig. 3. The whole course of the test was recorded using an integrated strain gauge sensor, which provided the data of force channel, and the measured length of the specimen was recorded using an extensometer MFA500. The test specimen was loaded and the test evolution was recorded until the failure of the tested material.

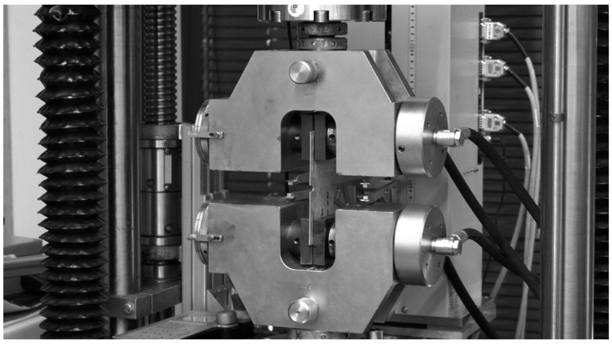


Fig. 3 *Arrangement of Plane Strain Test*

Measured data were subsequently processed using the software Origin 2020. Initial dependence of the force on the absolute elongation (working diagram) was recalculated to receive the required true stress-strain curve (dependence of the true stress on the true strain). Such final dependence was further mathematically described for the possibility of its utilization in the numerical simulation by the Krupkowski law – see equation 1. [10].

$$\sigma = C.(\varphi_{pl} + \varphi_0)^n \; [MPa], \tag{1}$$

Where:
σ…True stress [MPa],
C…Strength coefficient [MPa],
n…Strain hardening exponent [-],
φ_{pl}…Plastic true strain [-],
φ_0…Offset of true strain [-].

3 Results

Resulting values of the selected mechanical properties (proof yield strength $R_{p0,2}$, ultimate strength R_m) and also values of the approximation constants arising from the approximation resulting stress-strain curve by the Krupkowski law (generally power-law function) is, together with the rolling directions, summarized in Table 1.

Tab. 1 *Selected mechanical properties and values of the approximation constants for material Amag 6000*

Rolling direction [°]	$R_{p0,2}$ [MPa]	R_m [MPa]	C [MPa]	n [-]	φ_0 [-]
0	**185.38**	**231.98**	**408.29131**	**0.16318**	**0.00254**
45	**171.78**	**212.41**	**392.24036**	**0.17359**	**0.00350**
90	**171.14**	**224.53**	**409.72399**	**0.18589**	**0.00417**

In Fig. 4 is shown the resulting dependence of the true stress on the true strain (stress-strain curve) under the plain stress state of the tested specimen regarding the individual rolling directions 0°, 45°a 90°. In Fig. 5 is then illustrated mathematical description of this curve using the Krupkowski law for the rolling direction 0°.

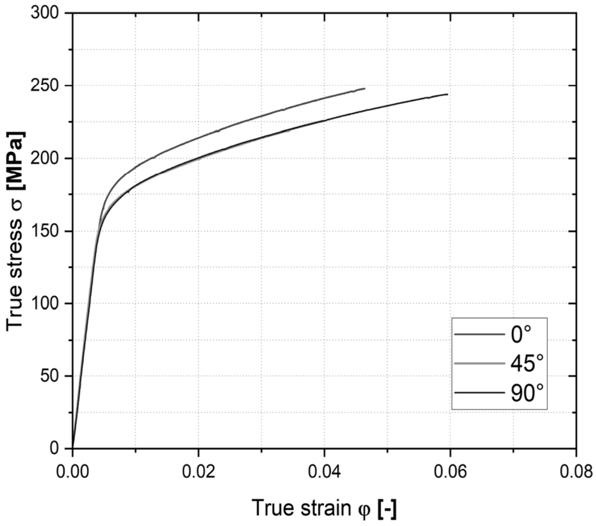
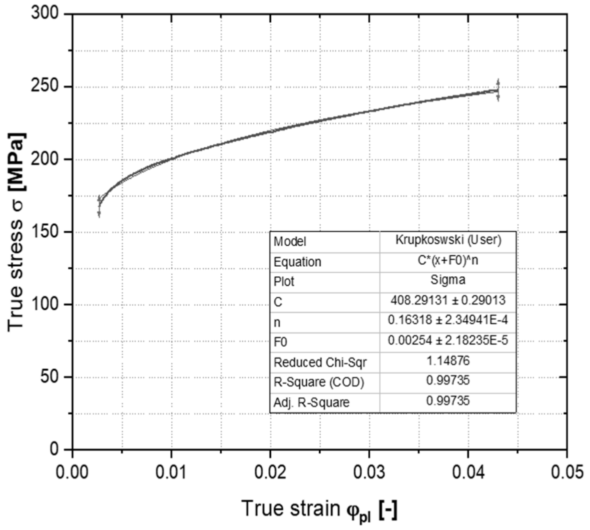


Fig. 4 *True stress-strain curves for the selected rolling directions 0°, 45°a 90°*



Model	Krupkoswski (User)
Equation	C*(x+F0)^n
Plot	Sigma
C	408.29131 ± 0.29013
n	0.16318 ± 2.34941E-4
F0	0.00254 ± 2.18235E-5
Reduced Chi-Sqr	1.14876
R-Square (COD)	0.99735
Adj. R-Square	0.99735

Fig. 5 *Approximation of the hardening curve for the rolling direction 0°*

4 Conclusion

The aim of this paper was to monitor the material mechanical properties and deformation behaviour of aluminium alloy designated as Amag 6000 under the plane stress conditions in a deformed body. This was carried out by means of the plane strain test. Shape of the testing specimen ensured the achievement of plane strain conditions. The selected mechanical properties and the hardening curves of the tested material under a given loading method are shown in the results section above with respect to the different rolling directions. Finally, these resulting hardening curves were mathematically approximated using the Krupkovski law (power-law function) - see results. Approximations of the hardening curves were performed in order to describe them mathematically. Such description can be further used e.g. in the mathematical modelling of the forming process as another data input and material characteristic for a more accurate definition of material computational models in the environment of the numerical simulations. Such approach should contribute to a better description of the material deformation and its subsequent spring-back.

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