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INFLUENCE OF EFFECTIVENESS SPEED IN MECHANICAL PROPERTIES OF AW6060 T66 (PA38) ALLOY

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Abstract

The article examines the effect of the change in the speed of deformation on the mechanical properties of AW 6060 alloy specimens, characterized by high mechanical strength, which is a material used in the shipbuilding industry. The theoretical basis for the influence of load speed on the mechanical properties of materials is presented. Static and dynamic tensile test was conducted on a universal testing machine. Dynamic stretching was performed on samples at 10^{-1} s^{-1} – 10^{2} s^{-1}. Done charts and tables showing results. Calculated in accordance with DIN EN ISO 6892-1 2010P total elongation and contraction of the sample. Comparison of the results of the study with the current knowledge of the subject. Material studies have shown that increasing the deformation rate results in an increase in the yield point and tensile strength. On the basis of calculations of the narrowing and elongation of the total sample, the material can be strengthened. The rate of deformation of the materials is favourable for their strengthening by increasing the limit of tensile strength. Given that most of the design is subject to dynamic loads and the aluminum alloy AW 6060 finds extensive use in shipbuilding and beyond, these are satisfactory results.

Keywords: *alloy aluminum, static load, dynamic load, yield strength, strength limit*

1. Introduction

Aluminum alloys exhibit an attractive combination of mechanical and physical properties such as high stiffness and low density, which favours their use to the greatest extent. They are used in shipbuilding as well as carriers for trucks, buses, trailers, rail cars, bridges, safety barriers, etc. Thus, increasing the use of aluminum alloy is a driving force for the proper understanding of how this material behaves in the specified Conditions and given parameters [11].

The plastic deformation of metals and alloys attracts the interest of scientists to understand their deformation, especially at fast speeds. Experimental studies have shown that the increase in the load rate, and hence the deformation rate, results in an increase in the yield point and strength [8]. The increase in the rate of deformation of the material causes its deformation by twisting. This results in an increase in the share of twin boundaries in a given grain. At medium deformation speeds, mechanical twins form and deform the material by slipping. This is accompanied by the transformation of the work of plastic deformation into heat and its dispersion. At higher deformation rates $\varepsilon \geq 10^{2}$ s^{-1}, the heat emitted by plastic deformation, due to very short operating time, will not be dispersed [1].

In addition, at deformation rates above $\varepsilon \geq 10^{-2}$ s^{-1}, the inertia forces of the structural element must be taken into account. There are so-called. "Speed effect", i.e. the dependence of mechanical properties on the speed of the load. In the works [5, 10] the results of investigations of changes in mechanical properties of steel for speed of deformation were presented 10^{-1}-10^{4} s^{-1}. The results of the research unambiguously demonstrate the increase of the strength properties of the tested steel. Therefore, the test results of aluminum alloy may be interesting.

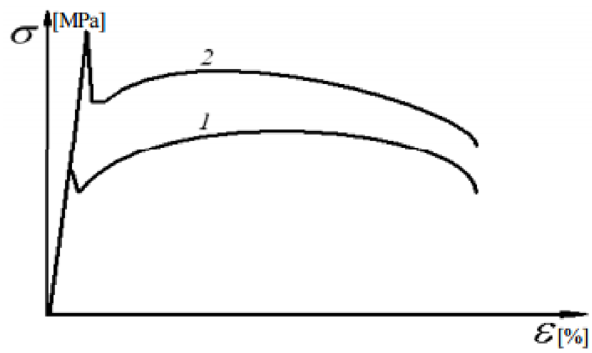

Fig. 1. The dependence graphs σ = f(ε) with the velocity of static (1) and dynamic (2) [5]

With respect to the dynamic loading of the sample, there remains a problem with the behaviour of the material, with varying load rates. In the presented work, a preliminary recognition of this problem was made on the example of aluminum alloy AW 6060 intended for shipbuilding. The aim of the study was to perform static and dynamic stretching tests along with the assessment of dynamic characteristics of marine materials at different deformation rates.

The article presents the theoretical basis of the problem and presents the influence of the loading rate on the physical characteristics of the material, Material sensitivity effect on the rate of deformation.

2. Influence of speed efficiency on mechanical properties of materials – theoretic base

In a single-axis stretching test, the total deformation is the sum of the uniform deformation (to the appearance of the constriction) and the constriction deformation (to break the sample) [1].

$$\varepsilon_c = \varepsilon_r + \varepsilon_p \, . \tag{1}$$

The uniform deformation size ε_r (until the appearance of the constriction) shows the material's ability to sustain plastic deformations. The total deformation value ε_c and the strength properties of the material are shown as the area under the stretching curve. A large area under the material's stretching curve proves that it has a large amount of energy that protects it from damage, thereby resulting in a high stress (strength limit).In a static stretch test, the initial stretching stage of the sample until the appearance of the narrowing occurs, characterized by a single axial stress. At the moment of constriction formation in the stretched sample, a triaxial tensile stress condition is generated (tangential and radial stress components) [4].

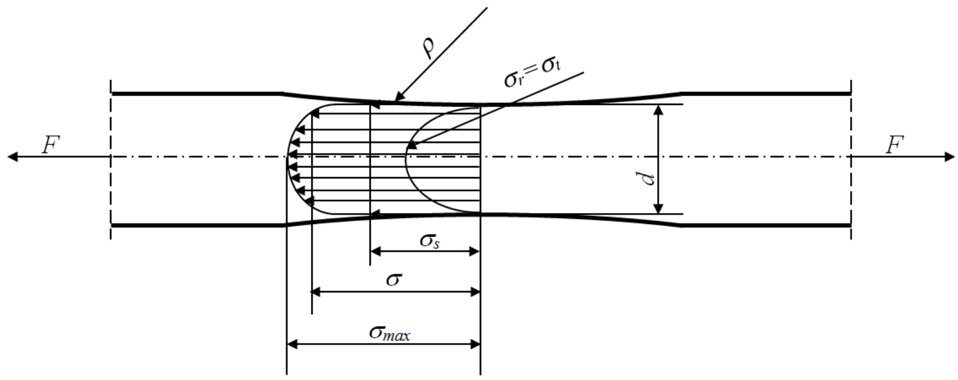

Fig. 2. Scheme of stress distribution in the neck of the stretched sample [3, 5]

Figure 2 shows the distribution of stresses in the sample neck with the diameter *d* under tension. The cross-section of the sample results in a complex stress state in the form of axial stress

σ_0, radial σ_r and circumferential σ_t. In the section x by the axes of the sample, the components of these stresses are determined by the dependence:

$$\sigma_o = \sigma_s \left(1 + \frac{a^2 - x^2}{2 \cdot \rho \cdot a}\right), \quad \sigma_r = \sigma_s \frac{a^2 - x^2}{2 \cdot \rho \cdot a}, \tag{2}$$

where:

a – the smallest ray in the neck,

ρ – the radius of the outer curvature forming the neck surface,

σ_s – stress corresponding to the yield point on the bottom of the neck.

During the stretching of the sample, when the neck is formed, deformation of the grains in the constriction area in the radial and peripheral directions is the same. Similarly, the values of the radial and peripheral tensile stresses are the same $\sigma_r = \sigma_t$. On the surface of the neck the values of these stresses are zero $\sigma_r = \sigma_t = 0$. Both main stresses causing deformation are equal, while the third must be zero. Based on Mohr's hypothesis, plastic deformation occurs when the maximum tangent stress reaches a critical value, i.e.:

$$\frac{\sigma_o - \sigma_r}{2} = \frac{\sigma_o - \sigma_t}{2} = \tau_{\max} = \sigma_s, \quad \frac{\sigma_r - \sigma_t}{2} = 0. \tag{3}$$

Based on the above relationships in the sample axis (for x = 0), the stresses take the maximum values.

$$\sigma_{o\max} = \sigma_s \left(1 + \frac{a}{2\rho}\right), \quad \sigma_{r\max} = \sigma_s \frac{a}{2\rho}. \tag{4}$$

In the cross-section of the forming neck, the average stress corresponds to the actual stress determined on the basis of the momentary load and the area of the cross-sectional area of the neck A.

$$\sigma_{\acute{s}r} = \frac{F}{A}. \tag{5}$$

During the deformation of the material in its structure, there are various processes associated with stacking and accumulation that make it difficult to slip. This results in deformation of the material. In the process of deformation, various defects in the form of weaves, cell walls or narrowed boundaries arise in the structure of the material, constituting an additional source of its strengthening. For materials with a particle size greater than 1 μm, uniform deformation increases as the rate of deformation increases. The increase in uniform strain is due to the interaction of the resulting shear microtas with the active slip mechanism on the grain boundaries. The resulting micro-shear shear causes cumulative energy deformation and thus delays the formation of the constriction in the tensile test. This means that the increase in total deformation for dynamic deformation of the materials is due to an increase in the uniform deformation [14].

With the increase of the deformation rate, the slippage across the grain boundaries is limited, and the resulting micropasms quickly transform into shear bands, resulting in deformation leading to the cracking of the sample [5, 10].

The deformation of high velocity materials leads to the change of isothermal conditions to adiabatic, and the work of plastic deformation converted into heat can influence the microstructure development, and thus the mechanical properties of the materials under investigation [4]. At high deformation rates, annihilation is inhibited and dislocation regression, i.e., typical healing effects [16].

The simplest model expressing the dependence of strain on the strain rate can be written as:

$$\sigma = C \cdot \dot{\varepsilon}^m, \tag{6}$$

where:
C, m – solid.

For a given type of solid material, these can be found in the literature [2, 3]. Inclusion of additional terms resulted in a unified, constitutive law known as the Johnson-Cook act:

$$\sigma = (A + B \cdot \varepsilon^n)\left[1 - \left(\frac{T - T_r}{T_m - T}\right)^m\right](1 + C \ln \dot{\varepsilon}), \tag{7}$$

where:
T_r – reference temperature (room temperature), T_m – melting temperature, A, B, C, m, n – solid.

In equation (7), the stress depends on the material's strength, the strain rate, and the temperature. Constants in equation (7) can be selected from literature for a given material type [2, 3].

There are a number of models that take into account the effects of deformation rates, temperature and other factors that affect deformation stresses. The most important of these is the Malverna model [9], Perzyna [12], Johnson-Cook, Zerille-Armstrong [6] and various character-microscopic or dislocating models [3, 6, 15]. Sometimes the use of these models requires a large number of factors and therefore many side problems, which makes it difficult correctly to interpret the experimental results [8].

3. Own research

Static and dynamic stretching samples were carried out on aluminum alloy, which according to EN 573-3 is designated AW 6060 T66, (AlMgSi (PA38)). Tab. 1 gives the chemical composition and heat treatment.

Tab. 1. Chemical composition of aluminum alloy AW 6060 T66

Condition of heat treatment	Sheet thickness, mm	Chemical composition									Lot number and certificate
		Mg	Mn	Ti	Zn	Cr	Si	Fe	Cu	Al	
T6	12	0.42	0.03	0.01	0.01	0.01	0.60	0.18	0.01	rest	35-925-0332-001

The geometry and dimensions of the samples for static and dynamic testing are shown in Fig. 3. The static and dynamic tensile tests were performed on a universal strength machine (Fig. 4).

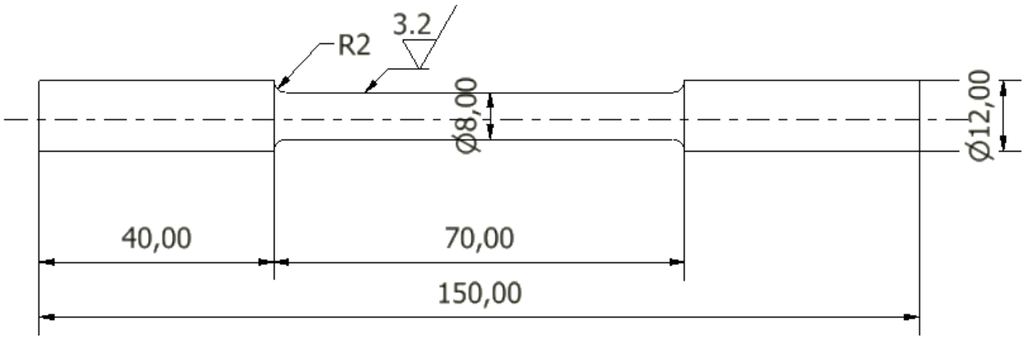

Fig. 3. Geometry of samples subjected to static and dynamic tensile testing according to PN-EN ISO 6892-1 2010P

4. Development and analysis of results of research

The study allowed to determine the effect of static and dynamic deformations on aluminum alloy AW 6060 T66 (Fig. 5).

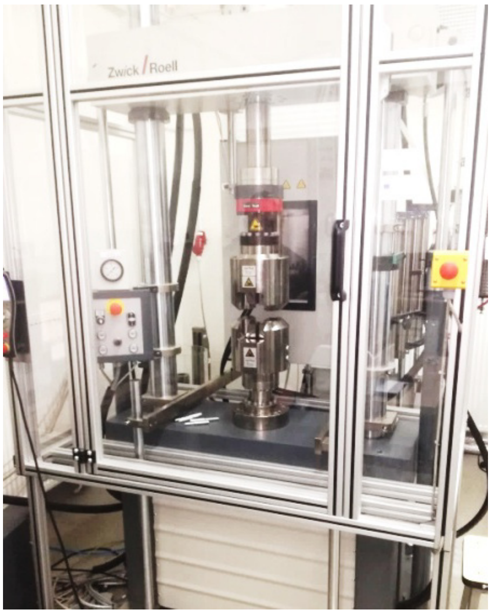

Fig. 4. Zwick Roell universal strength machine

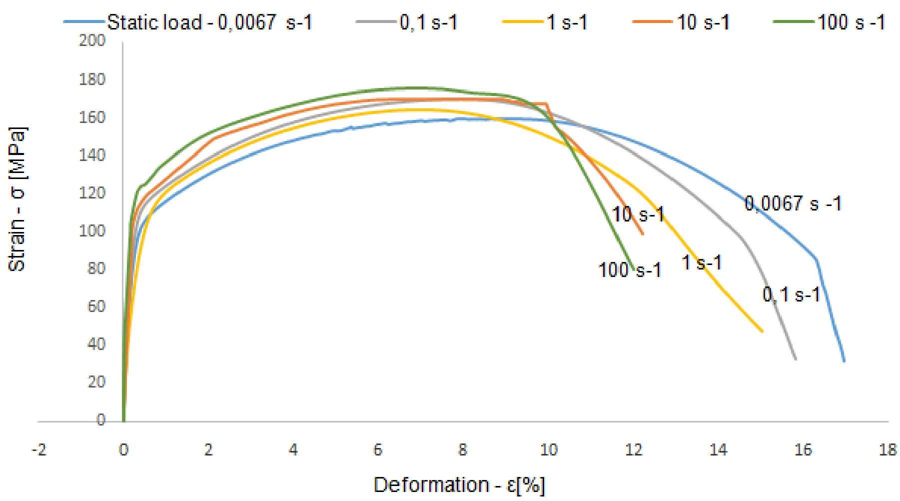

Fig. 5. Dependency graphs $\sigma = f(\varepsilon)$ with static and dynamic strain rates

By analysing the dependence graphs $\sigma = f(\varepsilon)$ with the static and dynamic deformation rates and the results presented in the table (Tab. 2), it can be stated that with the increase of the deformation rate the yield point increases (with a static tensile test of 112 MPa, 100 s^{-1} – 128 MPa), and hence the strength limit (with a static tensile test – 159.4 MPa, at a speed of 100 s^{-1} – 174.9 MPa). These results closely coincide with the theory presented in Chapter 2. "Speed effect", thanks to which we are dealing with the strengthening of the sample. In addition, a change in the breakthroughs, visible change in the structure of the material from elastic to plastic, can be observed.

Tab. 2. Static and dynamic properties of aluminum alloy AW 6060 T66

Speed [s^{-1}]	R_e [MPa]	R_m [MPa]	A_5 [%]	Z_0 [%]	t_{test} [s]
0.0067	112	159	16.6	52.2	–
0.1	118	165	15.8	50.7	5.22
1	122	170	14.9	42.2	2.04
10	120	170	12.3	38.7	0.82
100	128	175	11.7	33.3	0.47

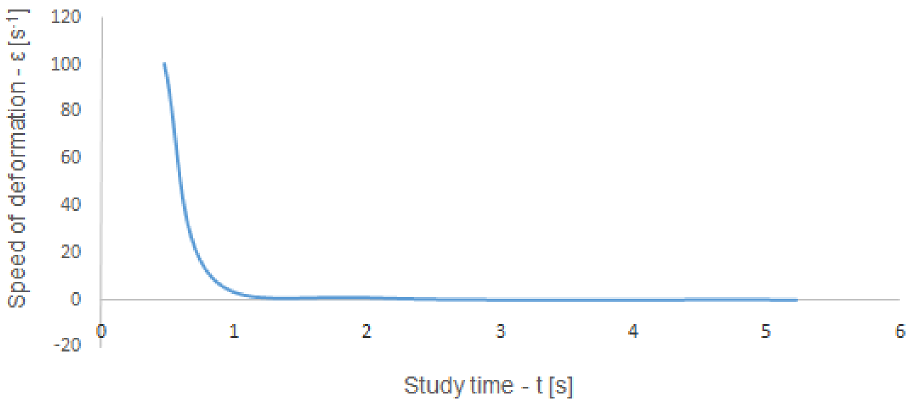

Fig. 6. Dependence of strain rate from test time for dynamic tensile test of alloy 6060 T66, based on data obtained after the test

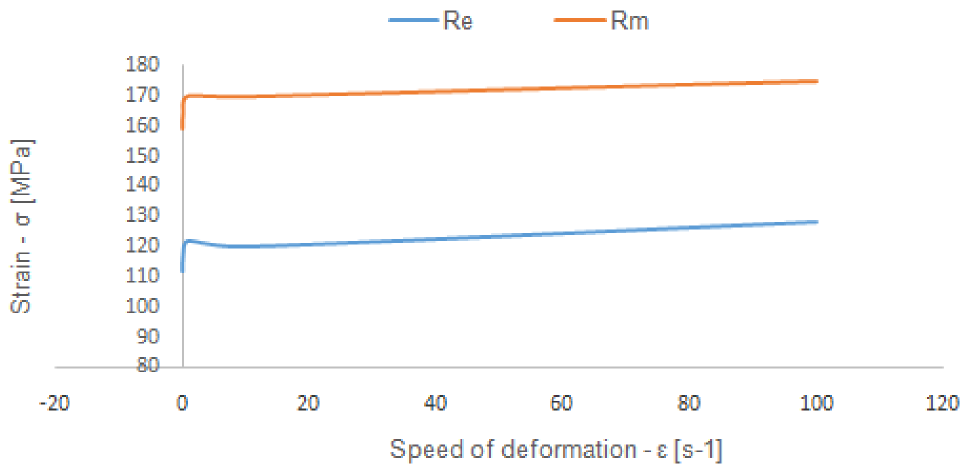

Fig. 7. Effect of deformation rate on yield strength and aluminum alloy strength 6060 T66

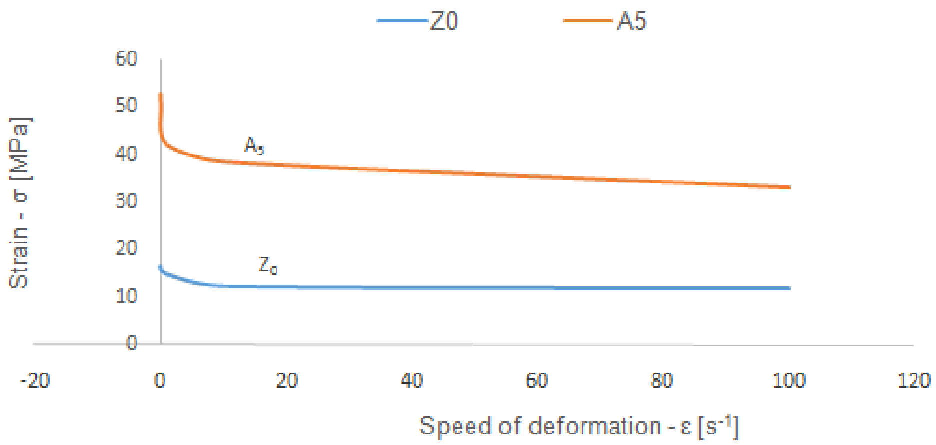

Fig. 8. The effect of the deformation rate on the total elongation (A5) and the constriction (Z0) of the aluminum alloy 6060 T66

The elongation parameters, as well as the narrowing of the sample (Tab. 2), which decrease as the velocity increases, further reinforces the effect of the material's strength, thus lessening the deformation. A_5 elongation at a static stretching test reached 16.65% and at 100 s^{-1} – 11.77%. The Z_0 static load was 52.85% while dynamic load was 100 s^{-1} – 33.33%. There is no clear increase in speed due to the specified maximum speed, which is 100 s^{-1} for the ZwickRoell Universal Strength Machine (Faculty of Mechanical, Maritime Academy in Gdynia) [7].

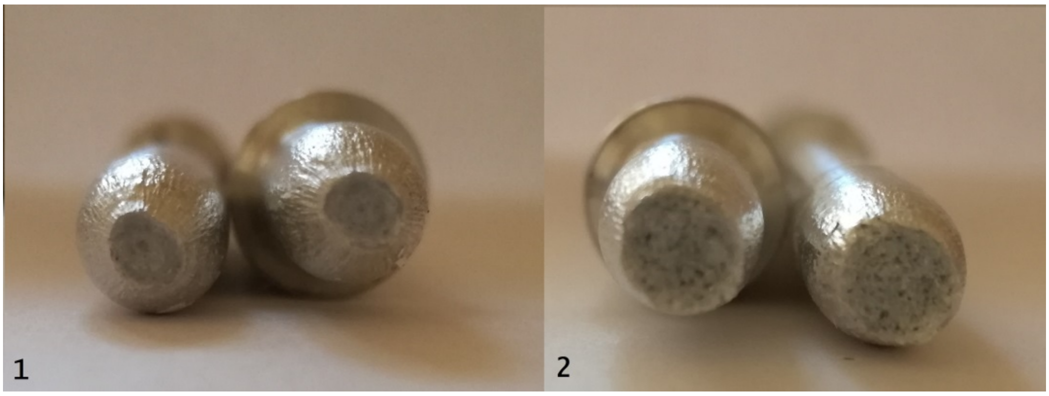

Fig. 9. Breakthroughs of selected samples: 1) after static stretching test, 2) after dynamic stretching with velocity 100 s^{-1}

5. Final remarks

The AW 6060 T66 aluminum alloy study has shown that as the speed of deformation increases, the yield strength and the tensile strength increase. At the same time, total elongation and narrowing decreases. In these samples, the material is strengthened so that it is able to withstand higher stresses. We are still dealing with the phenomenon of the so-called. Neck, but due to the increase in velocity, the structure of the material after the break of the sample also changes. Because most structures are subject to dynamic loads (especially in shipbuilding) and the selected aluminum alloy is used, the results are satisfactory.

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