Research of deformation ability of al-based alloy of system Al-Mg-Sc

Golovko A.N., Andreiev V.V., Boyarkin V.V., Frolov I.V.

National metallurgical academy of Ukraine, Department of Metal Forming

Gagarina av. 4, 49000, Dniepropetrovsk, Ukraine

The paper shows the ability to use of alloys of system Al-Mg-Sc. The problem of processing of that alloys without breaking is established. Experimental study of rolling and upsetting showed that the alloy of system Al-Mg-Sc is able to perceive a high deformation degree without fracture. It also revealed that the presence of nonhomogeneity structure of the billet leads to defects and often the complete destruction of the sample.

Key words: rolling, sediment, destruction, structure, billet

1. Introduction. Extending of payload for transport machineries is a problem with constant actuality. One of most effective ways for solution of this problem – increase of specific strength of materials in elements of machine`s body.

At present time in USA aerospace industry widely used Al-based alloys of 2nd, 3rd, 5th, 6th and 7th series. In Russian aviation technology is successfully used thermostrengthened aluminum alloys Al-Zn-Mg-Cu and Al-Mg-Cu [1]. But these alloys have a significant disadvantage – high propensity to hot cracking [2, 3].

The second problem of using thermostrengthened alloys is low specific durability of a welded seam in heat affected zone (HAZ) at level 0,5…0,7 of base value, that often eliminates advantages of using strengthening heat treatment.

A promising direction of solving the problem of weight reduction of vehicles in aerospace industry is alloying of welded non-thermostrengthened alloys of system Al-Mg by transitive metals, such as Scandium, Zirconium, etc. [4, 5]. Alloys of system Al-Mg-Sc have a high strength (380-420 MPa, depending on the alloy series), including at relative high temperatures, and good weldability.

The chemical composition of high – strength Al-Mg-Sc alloys, as a rule, consist 5,8-6,8% of Mg, 0,3-0,5% of Sc, 0,1-0,25% of Mn, 0,05-0,15% of Zr, etc. At the annealed condition alloys are used for the manufacture of welded and seamless construction, which operating at the temperature range from -196 °C to 156 °C, and has in all kinds of semi-finished products the strength value, which higher than those of alloys of the Al-Mg system [5].

Of these alloys are produced only semi-finished products (cold-rolled sheet, hot rolled plates, punched products). This is due to the fact that the high yield stress of these alloys requires more energy during forming, or even makes impossible to carry out the process. Also in the literature are not found recommendations for the process of plastic deformation to produce finished products such as pipes and profiles, that the most important for the aerospace industry.

Thus, the problem of definition of effective strain and energy-power parameters at the deformation of Al-Mg-Sc alloys is still open.

2. Experimental procedures. The aim of this paper is the experimental determination of the maximum strain rate at rolling, and upsetting of samples of Al-Mg-Sc alloy without breaking. The chemical composition of the alloy used in the investigation listed in Table 1. All experimental investigations were performed in laboratory of Department of Metal Forming at the National Metallurgical Academy of Ukraine.

The test specimens were prepared from extruded frame profile (Fig. 1). The specimens had rectangular cross section with dimensions in of 45×100 mm and thickness S from 6 to 12 mm, cut in the longitudinal direction, and the square - 52×52 mm with a thickness corresponding to the rectangular that was cut from the body of the mother profile (billet) in the transverse direction.

The end of the frame has been polished and etched in an acid solution with the purpose a visual analysis of macro-irregularities of metal structure in the cross section of the profile. The analysis showed that there is a high profile non-uniformity of the structure of the cross section: flanged parts have a greater degree of elaboration of the structure in comparison with the central part of the profile. This can be explained by the fact that in the process of pressing the profile was carried out with a small strain rate.

Rolling was carried out on a laboratory mill 200 with a flat (grooveless) rolls. Billet was heated in an electric resistance furnace to a temperature of 400-405˚ C, with intermediate heating to this temperature after each rolling pass. Temperature measurement was carried out with a wire-Ni-NiCr thermocouple. The final thickness of the rolled strip is 2 mm. The results of the experimental rolling, and in particular the degree of deformation and stretching, are shown in Table 2.

The analysis of experimental data exposed that in the process of rolling the Al-Mg-Sc alloy is able to perceive a high degree of pass strain (ε = 26-36%) without breaking. However, in rare cases the complete destruction of the specimen occurred in the first pass (Fig. 2). The heating mode and the strain rate of these specimens were identical to all other cases. This may be due to the deficiency of the billet, such as phase separation.

Further experimental researches were conducted on specimens upsetting to determine the maximum permissible strain rate by means of full factorial experiment 2^2 . Varying factors were the heating temperature of billets (T_{min} = 350 ˚C; T_{max} = 400 ˚C) and the strain rate (ε_{min} = 25%; ε_{max}=50%).

In preparing the specimens the two side faces and the end were polished and etched in an acid solution to the visual detection of surface defects of the billet.

On the surface of the specimens mechanical damages were not observed, but there is a high irregularity of the structure of the metal section of the specimen. The experimental results of upsetting shown in Table 3.

As shown in Fig. 3, specimens of the investigated alloy are able to perceive a high degree strain rate without breaking even at relative low temperature of heating. However, as in the rolling experiment, some specimens were destroyed after deformation (Fig. 4) that, as expected due to the high degree of nonhomogeneity of the structure of the cross-section of samples.

In paper [6] the authors have shown the adequacy of the mathematical model to determine the geometry and strain - kinematic parameters of the upsetting. Based on this model and determination the broader values of barreling in this research simulated an additional degree of strain rate at temperatures of 350 ˚C and 400 ˚C. The results of mathematical modeling are shown in Figure 5.

3. Conclusion. Thus, we can conclude that the alloy of system Al-Mg-Sc is able to perceive a high degree of strain rate without breaking, up to ε =50%. The optimum preheating temperature of the billets can be 350-400 ˚C. The presence of isolated cases of complete destruction of the specimens during deformation at relatively small degrees of strain rate indicates the importance of thorough preparation of the structure of the billet by the additional homogenization.

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Table 1. The chemical composition of the investigated Al-Mg-Sc alloys

Al [wt. %]	Mg [wt. %]	Sc [wt. %]	Mn [wt. %]	Cu [wt. %]	Zn [wt. %]	Zr [wt. %]	Fe [wt. %]	Si [wt. %]	Others [wt. %]
Basis	6,1	0,35	0,15	0,1	0,1	0,05	<0,3	0,0003	≈0,1

Fig. 1. Extruded frame profile made of Al-Mg-Sc alloy (main view)

Tab. 2 - Indicators of the deformation of rolled specimens

No. of specimens	Specimen size [mm]	The logarithmic stain by high of the specimen							Elongation factor by pass							Total strain	Total elong. factor
		Number of pass							Number of pass								
		1	2	3	4	5	6	7	1	2	3	4	5	6	7		
1	5×52×52	-0,15	-0,33	-0,3	-0,05	-	-	-	1,09	1,29	1,25	1,01	-	-	-	-0,83	1,76
2	6×52×52	-0,06	-0,41	-0,22	-0,17	-0,12	-0,18	-	1,04	1,40	1,10	1,21	1,10	1,10	-	-1,16	2,35
3	6×52×52	-0,16	-0,15	-0,32	-0,29	-0,23	-	-	1,2	1,16	1,12	1,29	1,26	-	-	-1,15	2,55
4	8×52×52	-0,13	-0,26	-0,23	-0,32	-0,26	-0,09	-	1,13	1,22	1,28	1,29	1,32	1,09	-	-1,29	3,26
5	6×52×100	-0,38	-0,13	-0,15	-0,26	-0,13	-	-	1,08	1,06	1,21	1,17	1,21	-	-	-1,05	1,97
6	8×52×100	-0,29	-0,14	-0,24	-0,10	-0,18	-0,26	-0,13	1,05	1,1	1,18	1,04	1,13	1,06	1,33	-1,34	2,24
7	10×52×100	-0,10	-0,36	-0,26	-0,25	-0,33	-0,22	-0,29	1,1	1,35	1,26	1,21	1,32	1,3	1,31	-1,81	5,08
8	12×52×100	-0,21	-0,40	-0,26	-0,23	-0,33	-0,26	-0,29	1,28	1,46	1,33	1,18	1,29	1,38	1,24	-1,98	6,45

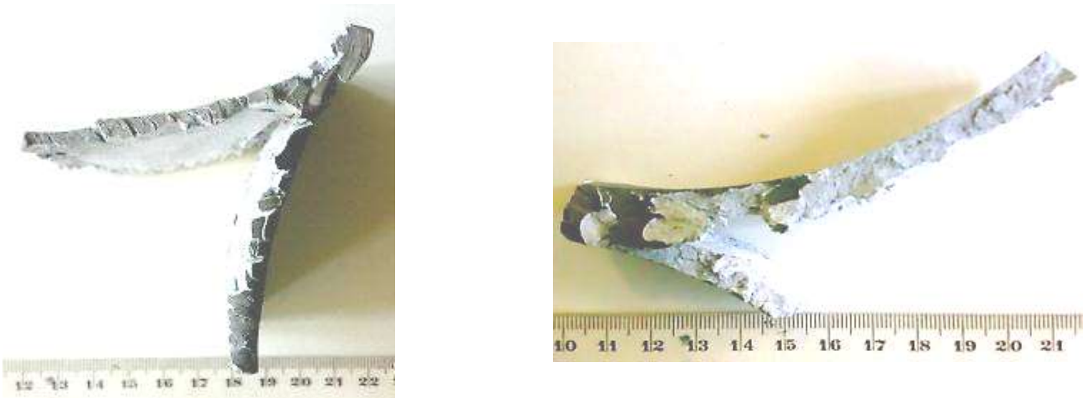
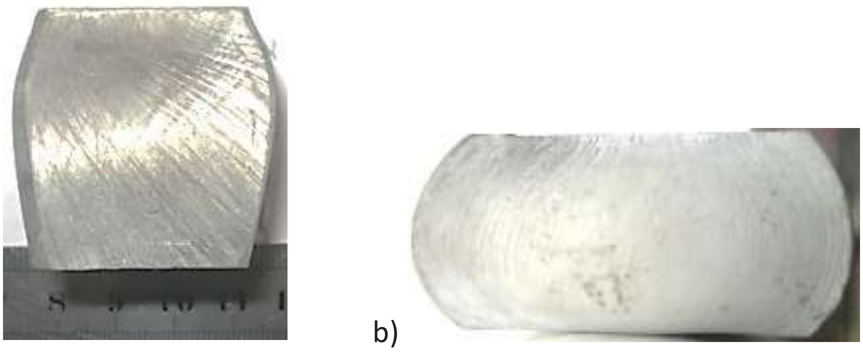


Fig. 2. Types of breaking specimens in the rolling process

Tab. 3. The experimental results of upsetting of billets Al-Mg-Sc alloy

#	H_0 [mm]	B_0 [mm]	T_0 [˚C]	ε [%]	H_1 [mm]	B_1 [mm]			T_{end} [˚C]	b\`
						top	middle	bottom		
1	46,0	29	350	0,24	34,8	30,5	34,7	27,1	250	1,20
2	38,4	29	350	0,5	19,2	33,3	44,2	34,4	229	1,31
3	42,0	28	400	0,23	32,2	29,2	36,8	29,2	319	1,26
4	33,8	30,2	400	0,52	16,3	37,7	49,2	37,6	223	1,31

b\` - coefficient of barrel



a) b)

Fig. 3. The general form of the specimen after the deformation: a – specimen No. 2 (ε = 25%, T0 = 400 ˚C); b – No. 5 (ε = 50%, T0 = 350 ˚C)

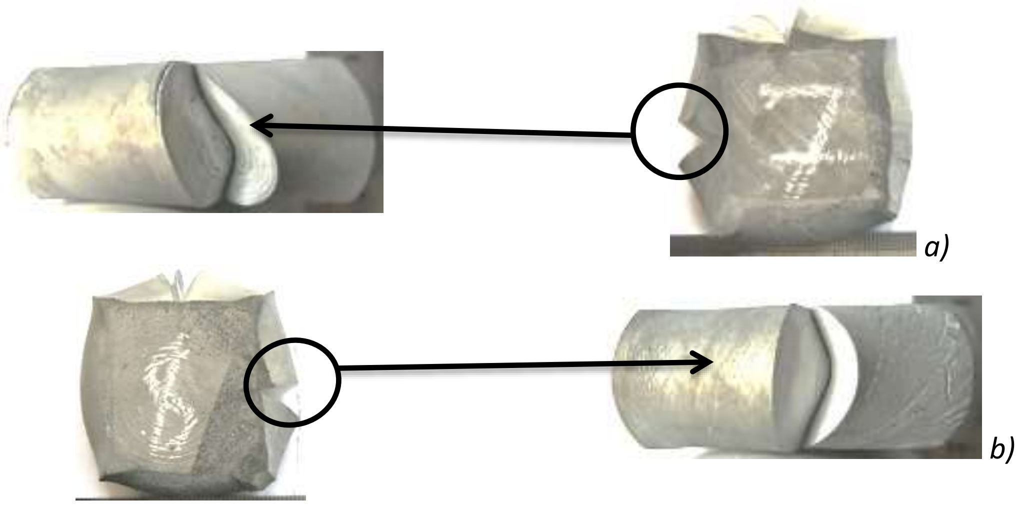


Fig. 4. General view of the braked specimens: a – specimen No. 7 (ε = 50%, T0 = 400 ˚C); b – specimen No. 8 (ε = 50%, T0 = 400 ˚C)

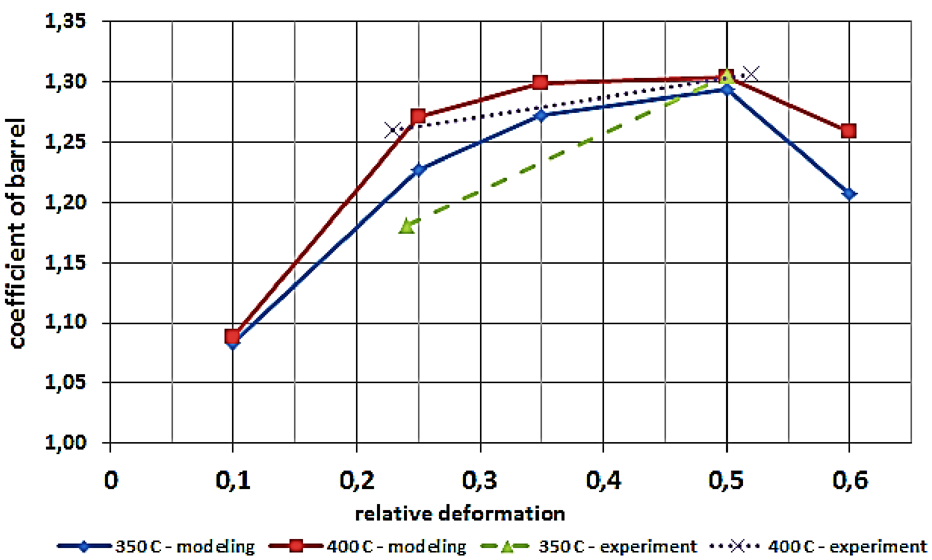


Fig. 5. Coefficient of barrel according to temperature and degree of deformation for Al-Mg-Sc alloy

Prof. Alexander N. GOLOVKO, p.g. student Vitalii V. ANDREIEV, assistant professor Vyacheslav V. BOYARKIN, prof. Iaroslav V. FROLOV

e-mail: vitaliiandreiev@gmail.com