Investigation of mechanical properties of cold-rolled, annealed and welded semi-finished products from the test alloys of Al-Mg system, economically alloyed with scandium

Baranov V.N.[1], Sidelnikov S.B.[1], Frolov V.F.[3], Zenkin, Y.Y.[2], Orelkina T.A.[1], Konstantinov I.L.[1], Voroshilov D.S.[1], Yakivyuk O.V.[1], Belokonova I.N.[1]

[1]Department of Metal forming, School of Non-Ferrous Metals and Material Science «Siberian federal university», Krasnoyarsk, 660025, Russia
[2]JSC «RUSAL Bratsk aluminum smelter», Bratsk, 665710, Russia
[3]LLC "RUSAL ETC", Krasnoyarsk, 660111, Russia

Email: d.s.voroshilov@gmail.com

Abstract. The results of experimental investigation of mechanical properties of sheet metal from an experimental aluminum alloys Al–Mg system alloyed with scandium have been represented. It was established that the deformed and annealed semi-finished products of these alloys have higher strength properties. Testing of welded samples made from these semi-finished products showed high corrosion resistance and strength of welded joints.

Keywords: aluminium alloys, scandium, sheet metal, mechanical properties, welded samples, corrosion resistance

1. Introduction

The problem of searching for new welded aluminum alloys having higher strength characteristics than existing industrial alloys of the Al-Mg system is most directly connected both with the creation of new, more sophisticated samples of new technology and with the solution of a number of national economic problems [1].

One of the most urgent problems of scientific and technical progress is the problem of increasing the weight perfection of missile and aircraft equipment, shipbuilding and the automotive industry. The main way to solve this problem is to increase the specific strength characteristics of structural materials by using new aluminum alloys with increased mechanical properties and corrosion resistance [2].

Studies in the field of creating alloys of the Al-Mg system doped with scandium and studying the properties of products made from them have been devoted many scientific publications, including foreign ones [3-12]. With the purpose of deeper studying the patterns of formation of mechanical and operational properties of products made of aluminum alloys economically alloyed with scandium, the employees of "RUSAL" together with scientists of the School of Non-Ferrous Metals and Materials Science of the Siberian Federal University have conducted a number of experimental studies in recent years with varying the chemical composition of alloys and regimes their processing, as well as produced batches of cast and deformed semi-finished products from them [13-16].

2. Experimental procedures

The ingots for rolling were obtained by casting alloys of the Al-Mg system with a scandium content of 0.1 to 0.24%. They were subjected to homogenization annealing according to the following regime: heating in furnace at a speed of 1,16 °C per minute to 350 °C; holding at this temperature for 11 hr; reheating to temperature 425 °C with speed 1,25 °C per minute; holding at this temperature for 8 hr; air cooling.

Each ingot was rolled according to a deformation scheme adopted, including hot rolling a billet 40 mm thick heated to a temperature of 450 °C, up to a thickness of 10 mm, and then cold rolling of these strips to a thickness of 1 mm. Next, the strip was annealed at a temperature of 300 °C and holding time of 3 hr. As equipment for rolling, the DUO 330 mill was used (table 1).

Table 1. Technical characteristics of the sheet rolling mill DUO 330

Parameter name	Value
Electric motor power, kW	90
The mains supply voltage is three-phase, V	380
Current frequency, Hz	50
Width of barrel rolls, mm	520
Diameter of rolls, mm	330
Maximum roll separation, mm	70
Rotational speed of rolls, rpm	10
Maximum rolling force, MN	1,55
The maximum rolling moment, MNm	0,82

In the course of rolling, samples were taken for testing the mechanical properties and the temporary tensile strength R_m, yield strength R_p and elongation A_{10} for each sample studied of alloys.

Mechanical properties after cold rolling at different degrees of deformation ε are given in table 2 (HR – after hot rolling, CR – after cold rolling at different degrees of deformation).

Table 2. Mechanical properties of samples from experimental alloys in a deformed state

Alloy	Sc,%	R_m, MPa				R_p, MPa				A_{10}, %			
		HR	CR			HR	CR			HR	CR		
			40%	60%	80%		40%	60%	80%		40%	60%	80%
1.	0.07	344	426	459	454	172	244	254	267	12.5	9.3	8.7	5.0
2.	0.09	350	438	470	494	225	237	256	274	12.2	8.2	7.4	4.8
3.	0.12	356	447	477	501	232	232	251	267	12.0	8.2	7.0	4.6
4.	0.13	373	460	478	505	235	232	257	372	11.7	8.3	7.0	4.2
5.	0.14	374	464	479	510	233	246	264	270	11.2	8.2	7.0	4.5
6.	0.14	360	465	480	513	245	295	314	278	10.6	8.1	7.0	4.4
7.	0.22	376	467	485	520	254	392	412	472	7.6	7.0	5.0	4.3
8.	0.24	380	476	490	554	250	395	414	488	7.0	6.3	4.6	4.2

The results of studies of the properties of the final products of rolling (annealed strips with a thickness of 1 mm) are given in table 3. Their analysis shows that the level of properties for experimental alloys containing scandium reaches elongation of values of about 21%. The yield strength of these alloys varies from 248 to 318 MPa.

Table 3. Results of studies of properties annealed strips of 1 mm thick

Alloy number	Tensile strength R_m, MPa	Yield strength R_p, MPa	Elongation A_{10}, %
1.	407	261	21.2
2.	412	248	14.8

3.	425	275	14.3
4.	435	276	12.8
5.	462	277	12.1
6.	463	278	12.0
7.	474	307	10.3
8.	487	318	9.2

Data on the strength properties of semi-finished products from experimental alloy 3 containing 0.12% scandium, in comparison with the analog alloy 5083, which does not contain scandium, are given in table 4 and showed that the strength characteristics of economically alloyed alloy increased to a considerable extent, both in the deformed and annealed state.

Table 4. Strength properties of samples of rolled products from experimental alloys in a different state

Sample thickness, mm	Condition	Strength properties, MPa			
		alloy 5083		experimental alloy	
		R_m	R_p	R_m	R_p
10	hot deformed	297	196	356	232
8	hot deformed	305	217	372	280
6	hot deformed	318	213	387	312
3	cold deformed	394	373	453	429
3	annealed	277	139	390	277
1	cold deformed	497	359	554	467
1	annealed	342	187	425	275

To study the properties of the welded seam, the resulting strips were welded along (method 1) and across (method 2) direction of deformation by means of argon-arc welding with filler wire from alloy 01570 (Figure 1), obtained by the method of combined casting and rolling-extruding with subsequent drawing. The mechanical properties of rods and wire are shown in table 5. Welding was performed using TIG-AC technology using a welding machine TIG200P.

Figure 1. View of welded samples

Table 5. Mechanical properties of rods and wires from alloy 01570

Alloy	Mechanical properties of semi-finished products

	Rod Ø 9 mm			Wire Ø 3 mm	
	Tensile strength R_m, MPa	Elongation A_{10}, %	Wire condition	Tensile strength R_m, MPa	Elongation A_{10}, %
01570	320	9.9	Hardened	432	2.2
			Annealed	340	17.5

To assess the nature and degree of corrosion destruction of the investigated alloys, including in the weld zone, in accordance with State Standard 9.021-74 accelerated tests on the intergranular corrosion were performed (IGC). To do this, strips 3 mm thick were used, as well as samples welded from them with a welded joint along and across the direction of deformation. From the strips, tensile samples were prepared and placed in a solution containing sodium chloride solution and 0.3% hydrogen peroxide (58 g/l NaCl + 10 ml/l 33% solution H_2O_2). The temperature of the solution was 18-25°C, and the test duration is 24 hr. On all sides samples were washed with a solution, as shown in Figure 2. The samples were degreased with isopropyl alcohol before the IGC test and dried with filter paper. Then, etching was carried out for 2 minutes in a solution containing 50 ml of nitric acid (70%), 5 ml of hydrofluoric acid (48%) and 945 ml of water, at a solution temperature of 95±3°C; then the samples were washed in cold water and clarified in 25-30% nitric acid solution, then washed again and dried with filter paper. After the end of the test, the samples were washed under running water and dried in furnace at a temperature of 100±5°C within 5 minutes.

After that, tensile tests were carried out and the mechanical properties of the samples in the weld zone.

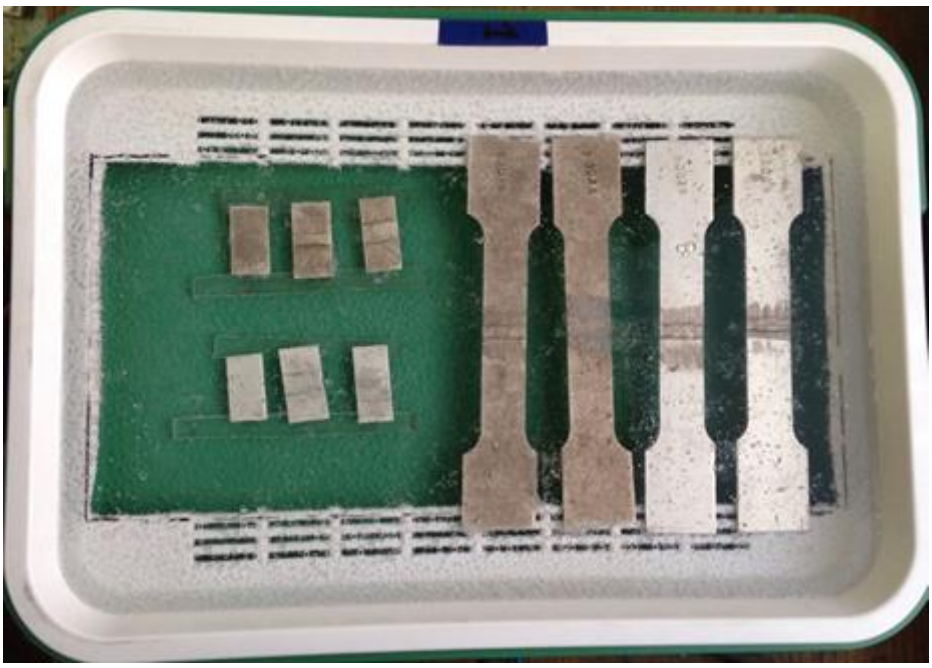

Figure 2. Scheme of laying samples for tests on the IGC

The results of investigations for some alloys are given in table 6. Tests for intergranular corrosion of samples after welding showed high corrosion resistance of welded joints, while the weld strength is 0.75-0.85 of the strength of the base metal.

Table 6. Mechanical properties of welded samples from experimental alloys

Number of alloy/sample	Method for obtaining samples	Mechanical properties of samples after welding and annealing		
		R_m, MPa	R_p, MPa	A_{10}, %
2/1	1	362	246	6.0
2/2	2	353	293	3.3
3/1	1	361	250	6.0
3/2	2	334	245	2.6
5/1	1	351	242	5.7
5/2	2	333	240	3.3
6/1	1	344	250	5.8
6/2	2	339	246	3.1

3. Conclusion

Thus, the conducted studies made it possible to obtain data on the level and patterns of changes in mechanical properties from the total degree of deformation of rolled products from new alloys of the Al-Mg system doped with scandium in the range 0.10-0.24%, in a different state (hot deformed, cold deformed, annealed and welded). These data will be used in mastering the technology of casting and processing of these alloys in industrial conditions.

Acknowledgements

The manuscript was prepared using the results of the work carried out during the project 03.G25.31.0265 “Development of economically alloyed high-strength Al-Sc alloys for use in road transport and navigation” in the framework of the Program for the implementation of complex projects for the creation of high-tech production, approved by the Government of the Russian Federation on April 9, 2010 №218.

References

[1] Gorbunov Y A 2015 *Journal of Siberian Federal University. Engineering & Technologies* **5(8)** 636–45

[2] Belov N A 2010 *Phase Composition of Industrial and Advanced Aluminum Alloys* (Moscow: MISiS) p 511

[3] Chunchang S, Liang Z, Guohua W, Xiaolong Z, Antao C and Jiashen T 2017 *Materials Science & Engineering* **A680** 232–38

[4] Pedro H R P, Ying C W, Yi H and Terence G L 2017 *Materials Science & Engineering* **A685** 367–76

[5] Mondol S, Alamb T, Banerjee R, Kumar S and Chattopadhyay K 2017 *Materials Science & Engineering* **A687** 221–31

[6] Mengjia L, Qinglin P, Yunjia S, Xue S and Hao X 2017 *Materials Science & Engineering* **A687** 298–305

[7] Buranova Y, Kulitskiy V, Peterlechner M, Mogucheva A, Kaibyshev R, Divinski S V and Wilde G 2017 *Acta Materialia* **124** 210–24

[8] Fuller C B 2005 *Acta Materialia* **53(20)** 5415–28

[9] Ryset J and Ryum N 2005 *International Materials Reviews* **50(1)** 19–44

[10] Toropova L S, Eskin D S, Kharakterova M L and Dobatkina T V 1998 *Advanced Aluminum Alloys Containing Scandium: Structure and Properties* (Amsterdam: Gordon and Breach Science Publicshers) p 175

[11] Ibrokhimov S Zh, Eshov B B, Ganiev I N and Ibrokhimov N F 2014 *Izvestia of Samara Scientific Center of the Russian Academy of Sciences* **16(4)** 256–60

[12] Ibrokhimov S Zh, Eshov B B and Ganiev I N 2013 *Reports of the Academy of Sciences of the Republic of Tajikistan* **56(6)** 472–75

[13] Yakivyuk O V, Sidelnikov S B, Dovhzenko N N, Frolov V F, Krohin A Yu, Bezrukikh A I and Frolov V A 2016 *Non-Ferrous Metals and Minerals 2016, Collection of Abstracts* 262–63

[14] Frolov V A, Yakivyuk O V, Frolov V F and Voroshilov D S 2016 *Collection of Materials XVII International Scientific and Technical Ural School - a Seminar of Metal Scientists - Young Scientists. Part 2* 113–17
[15] Frolov V A 2016 *Innovative Processes of Metal Working With Pressure: Materials 2 of the Int. Scientific and Practical Conf.*, ed M V Chukin (Magnitogorsk: Magnitogorsk State Technical University named after G I Nosov) pp 23–24
[16] Baranov V N, Sidelnikov S B, Bezrukikh A I and Zenkin E Y 2017 *Tsvetnye Metally* **9** 83–88