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IMPACT OF THE TYPE OF QUENCH AGING AFTER HYPERQUENCHING ON THE MECHANICAL STRENGTH PROPERTIES OF AW-7020 ALLOY

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Abstract

The article attempts to determine the influence of selected types of the heat treatment on the strength properties of the AW-7020 alloy used in the shipbuilding industry. The text presents information on the applied types of heat treatment. There are presented the results of the static tensile test of the material after its earlier hyperquenching and aging (natural and artificial) as well as comparison to the test results of the alloy without heat treatment. To illustrate the nature of the supersaturation and aging process, a test was carried out for a series of samples in a transitional state. During the tests for all the samples were determined: elongation at rupture and reduction of area at fracture, strength limit Rm and proof stress Re0.2. The results of the tests showed that the choice of the type of aging after saturation has significant importance for the strength properties of the AW-7020 alloy. It has been shown that it is possible to significantly accelerate the achievement of higher strength properties of the tested alloy, replacing the natural aging of the material with artificial aging.

Keywords: *AW-7020 alloy, age hardening, natural aging, artificial aging, hyperquenching strength limit, rupture elongation, fracture area reduction, intermediate state, age process hardening*

1. Introduction

Aluminum alloys have an attractive combination of mechanical and physical properties, such as relatively high stiffness and low specific weight. For constructors who design means of transport they are one of the basic groups of materials used in their work. From the moment of mastering the technology of producing aluminum alloys, it is still trying to improve their properties. Changes in the chemical composition of alloys are made by using various types of additives to improve strength properties. Attempts are also made to improve technological processes, including heat treatment, in order to increase the fatigue strength of alloys for example. However, changes do not always go hand in hand with the simultaneous increase of all physical properties. On the example of a batch of samples made of aluminum alloy with the AlZn5Mg2CrZr marking, it has been proved that the addition of Cr, Zr and Ti additives to the original material AlZn5Mg1 improves the strength properties but decreases the plastic properties of the material. At the same time, it was shown that the type of heat treatment, i.e. variable cooling rate after supersaturation, affects the fatigue and corrosion properties of the tested material [1].

Many aluminum alloys used in shipbuilding or as load-bearing elements of trucks, buses, trailers and railway wagons enforce the need for proper understanding of how these materials behave under specific conditions and at given operational parameters [2].

The influence of heat treatment of metals and their alloys attracts the interest of not only scientists but also, above all, constructors and technologists. The use of an accelerated technological heat treatment process without significant damage to the physical and physico-chemical properties of the material can bring significant savings in the production process.

Limitation of the need for multi-week storage of plates or profiles made of the AW-7020 alloy can be indicated as an example. The storage is required in the natural aging process of this material after supersaturation.

The aim of the conducted tests was to determine the influence of aging type (natural and artificial aging) of AW-7020 alloy samples on strength properties determined in a static tensile test of metals carried out in accordance with PN-EN ISO 6892-1_2010P [7] on a universal testing machine. The comparison of the tests results to the results obtained for samples from the material in delivery state, i.e. those that have not been subjected to supersaturation and aging, shows how the selected heat treatment and in particular the type of aging changes the properties of the alloy. In addition, the strength test for the material in the transition state, i.e. 6 days after supersaturation but without subjecting the samples to artificial aging, allowed visualizing the scale of changes in the strength properties of the selected alloy caused by the aging process.

2. The type of material, its chemical composition, and parameters of the applied heat treatment for the samples used for the tests

The quality sheet 7020 F35-type made according to the EN-AW 7020 standard was selected for the production of samples that were then used for testing. The chemical composition of the sheet is shown in Tab. 1. This alloy was choose due to alloying elements used in it, in particular due to the content of Ti, which ensures fine graining of the alloy structure by reducing the size of grains and the proportion of large secondary phases in the grain matrix and at their boundaries [1, 6].

As a kind of heat treatment, precipitation strengthening called age hardening or particle hardening was selected. In principle, the precipitation strengthening of aluminum alloys is based on two processes, namely solid solution supersaturation and then aging. The precipitation strengthening, which consists of the operations mentioned above, can be carried out only for alloys, in which the range of variable solubility of the alloying element occurs with the temperature change. Those are 2xxx, 6xxx and 7xxx series of alloys, where on the phase systems a decrease in the solubility of at least one alloy element is clearly visible with a temperature decline [3, 4].

Precipitation strengthening of aluminum alloys is effective if foreign atoms are introduced and dislocated into crystal structure of the basic metal and if in its structure, it will be possible to create an adequate number of very strong and stable precipitations of intermetallic phases preferably in the form of uniformly distributed and fine particles. In order to obtain such a structure in the precipitation strengthening process, the Ti-alloy-element was added to the selected material [1, 6].

Tab. 1. The chemical composition of the AW-7020 alloy quality sheet (according to Declaration of Conformity HP-Stal No. KJ / 2014/09192 dated 09/09/2014)

Material type	Chemical composition [%]										Melting number	Norms
	Zn	Mg	Cr	Zr	Ti	Fe	Si	Cu	Mn	Al		
7020 F35	4.53	1.22	0.19	0.13	0.03	0.24	0.10	0.14	0.24	rest	1-12--9007	EN AW 7020 EN 10204:2004

The shape and dimensions of the samples were selected taking into account the physical and chemical properties of the alloy AW-7020. This material achieves maximum strength properties when the cooling rate after supersaturation is around 0.5ºC/s. Cooling after supersaturation of this alloy should therefore be carried out in the air stream or by immersion in water at ambient temperature [5]. The parameters of the heat treatment the samples were subjected to be shown in Tab. 2.

Strength properties of precipitation strengthened samples were compared depending on the type of aging i.e. by comparing samples marked as “2” (natural aging) and marked as “3” (artificial aging, accelerated) with each other. Samples designated as "0" were reference material. To illustrate the changes brought by the process of natural aging and accelerated aging, it was decided to subject to the strength tests samples designated as “1”, i.e. those which after supersaturation were cooled rapidly in water at ambient temperature and then were matured for 6 days but were not subjected to artificial aging.

Tab. 2. Heat treatment parameters and the way of sample determination

Material type	Sample designation	Heat treatment parameters			Designation of heat treatment
		Supersaturation		Aging	
		Temperature/ /time	The cooling method after supersaturation		
AW-7020 F35	0A, 0C, 0D	—	—	—	Delivery state
AW-7020 F35	1A, 1B, 1C	450ºC / 1.5 hours	water at 20ºC	air at 20ºC for 6 days	Intermediate state
AW-7020 F35	2A, 2B, 2C	450ºC / 1.5 hours	air at 20ºC	air at 20ºC for 90 days	ta
AW-7020 F35	3A, 3B, 3C	450ºC / 1.5 hours	water at 20ºC	air at 20ºC for 6 days then heating: at 95ºC for 15 hours and at 150ºC for 10 hours	tb_{21}

In parallel with the strength tests of the above-described group of AW-7020 alloy samples the tests of changes in the structure of this alloy and tests of hardness changes of individual states marked as “0”, “1”, “2” and “3” were carried out at the Maritime University of Gdynia. The results of the tests are presented in another article of this journal.

3. Methodology of tests

A static tensile test was carried out on a universal testing machine MPMD P10B-type from Zwick & Roell with an Epsilon Model 3542 extensometer (Fig. 3). The test results were recorded using Zwick & Roell software – testXpert II version 3.61.

Samples of the tested material were made from the quality sheet of the 7020 F35-type 12 mm thick along the rolling direction. Shape (Fig. 1 and 2) and dimensions of samples (Tab. 3) were made in accordance with the recommendation of PN-EN ISO 6892-1: 2010 [7].

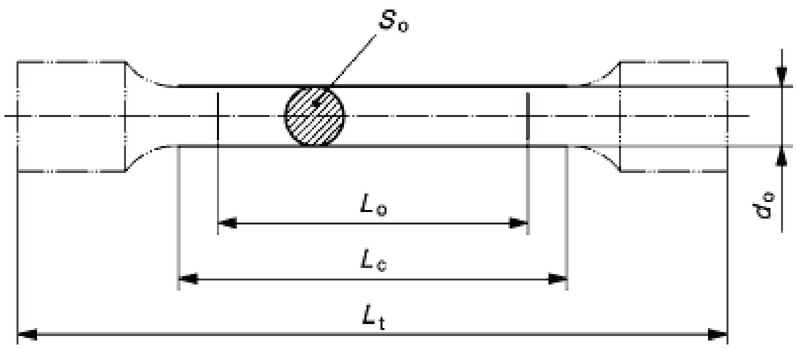

Fig. 1. Tensile geometry of the samples according to the recommendations of PN-EN ISO 6892-1:2010

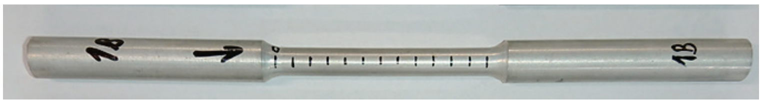

Fig. 2. One of the samples of group “1” before the test

Tab. 3. Dimensions of test samples

L_t [mm]	L_c [mm]	L_o [mm]	d_0 [mm]	S_0 [mm^2]
180	60	50	8	50.27

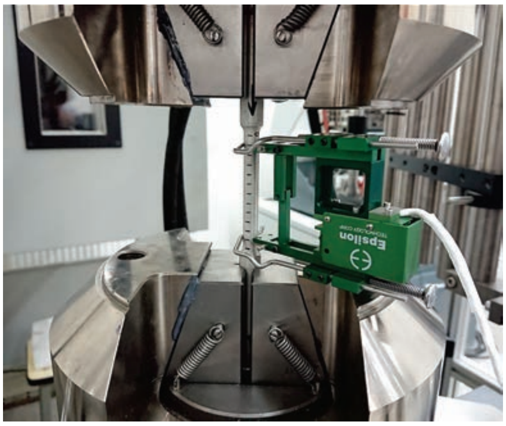

Fig. 3. The sample embedded in the terminals of the testing machine with the Epsilon Model 3542 extensometer mounted

4. Own tests

The static tensile test was carried out on samples made of AW 7020 aluminum alloy F35-type, which were prepared and described as in Chapter 1 of this publication. The method of testing is described in Chapter 2. Tab. 4 below shows the test results obtained from the Zwick & Roell program testXpert II version 3.61 but with the exception of the value of reduction of area at fracture (Z), which were calculated after the break of samples in accordance with the principles described in the PN-EN ISO 6892-1_2010P standard [7].

Tab. 4. List of test results for all samples

sample designation	m_E [GPa]	$R_{p0.2}$ [MPa]	R_m [MPa]	F_m [kN]	A_{50} [%]	L_c [mm]	L_0 [mm]	d_0 [mm]	S_0 [mm²]	Z [%]
0A	70.84	297.81	380.27	19.07	10.90	60.00	50.00	7.99	50.14	17.89
0C	70.49	292.87	379.30	19.11	12.13	60.00	50.00	8.01	50.39	18.75
0D	70.43	292.59	378.93	19.09	13.30	60.00	50.00	8.01	50.39	18.53
1A	73.76	222.45	354.18	17.63	13.51	60.00	50.00	7.96	49.76	22.44
1B	72.37	220.58	354.01	17.79	14.68	60.00	50.00	8.00	50.27	22.78
1C	71.42	220.99	353.83	17.79	13.58	60.00	50.00	8.00	50.27	22.56
2A	72.35	250.87	397.16	19.91	14.45	60.00	50.00	7.99	50.14	19.25
2B	70.72	244.85	389.81	19.79	14.55	60.00	50.00	8.04	50.77	20.25
2C	71.07	247.77	393.04	19.90	14.34	60.00	50.00	8.03	50.64	19.38
3A	70.99	360.07	413.94	20.86	12.43	60.00	50.00	8.01	50.39	45.93
3B	72.56	361.38	416.06	20.86	13.44	60.00	50.00	7.99	50.14	46.21
3C	72.55	360.60	414.90	20.80	13.41	60.00	50.00	7.99	50.14	47.67

Figure 4 shows the stretching graphs in the system (σ, ε) for all tested samples. The figure clearly shows the range of elongation measured with the Epsilon Model 3542 extensometer (measuring range up to 4.9 mm) and the range of elongation at rupture measured by the cross--beam (traverse) movement of the testing machine (the range corresponding to an absolute elongation of over 4.9 mm).

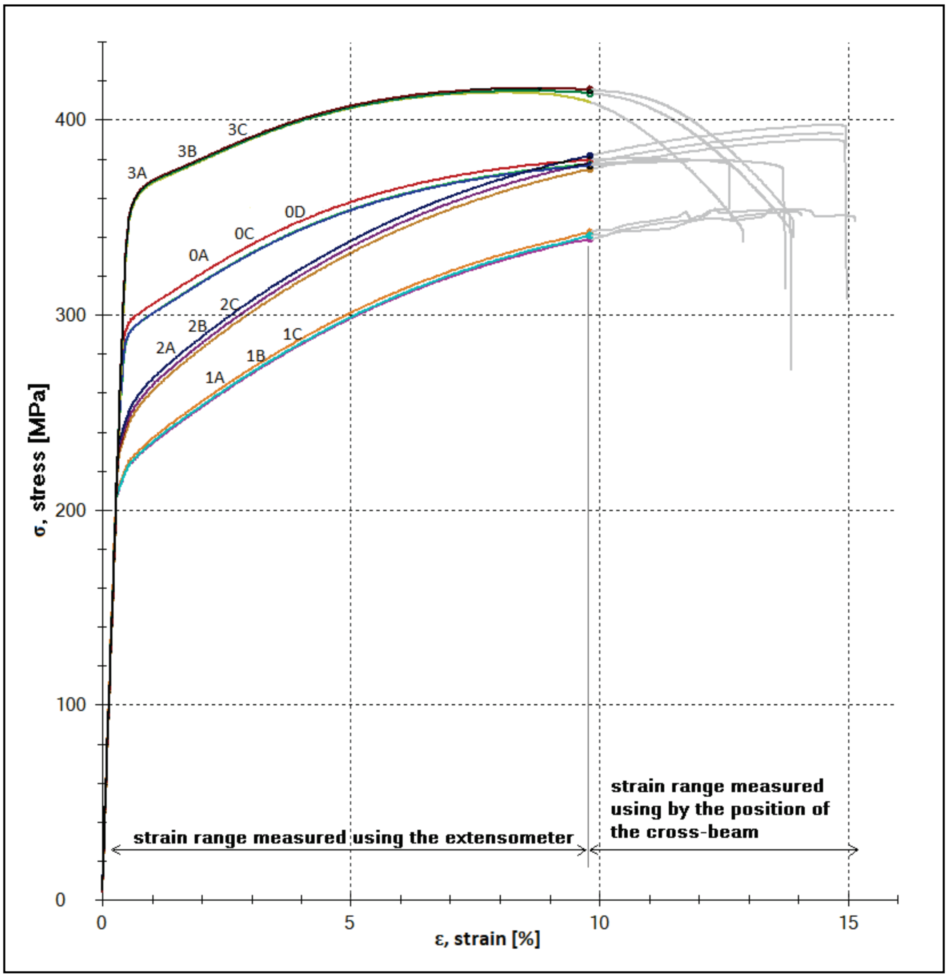

Fig. 4. Aggregate graphs of dependence σ = f (ε) for all tested samples

5. Development and analysis of test results

Comparison of strength properties of material after artificial aging (accelerated) of samples 3A, 3B, 3C and natural aging of samples 2A, 2B, 2C. The tensile graph (Fig. 5) clearly showed an increase in the strength limit (414 MPa < R_m < 416 MPa) for alloy samples aged artificially against to the strength limit (390 MPa < R_m < 397 MPa) for samples that were aged naturally.

The conducted test allowed to determine the influence of the selected type of artificial and natural aging (samples of group "3" and "2" respectively) on the strength properties of AW 7020 alloy F35-type, relative to the properties of material which was not subjected to precipitation strengthening (samples "0") – Fig. 5. The figure clearly shows the increase of strength properties at static tension for samples subjected to precipitation strengthening. R_m for samples aged artificially ranged from 414 MPa to 416 MPa. R_m for samples aged naturally ranged from 390 MPa to 397 MPa, and R_m for samples not strengthened ranged from 379 MPa to 380 MPa.

To illustrate the essence of the precipitation strengthening process, tests were carried out on a series of samples marked as group "1", which after supersaturation were cooled rapidly in water at 20ºC and then aged for 6 days in air at ambient temperature but not subjected to artificial aging.

The test results of these samples were compared with the results of tests for samples of group “3” supersaturated and chilled in the same way, which after 6 days of aging in air at ambient temperature were then heated to 95ºC for 15 hours and 150ºC for 10 hours (Fig. 6). The graph also shows the results for samples in the delivery condition, i.e. not subjected to precipitation strengthening (samples of group “0”).

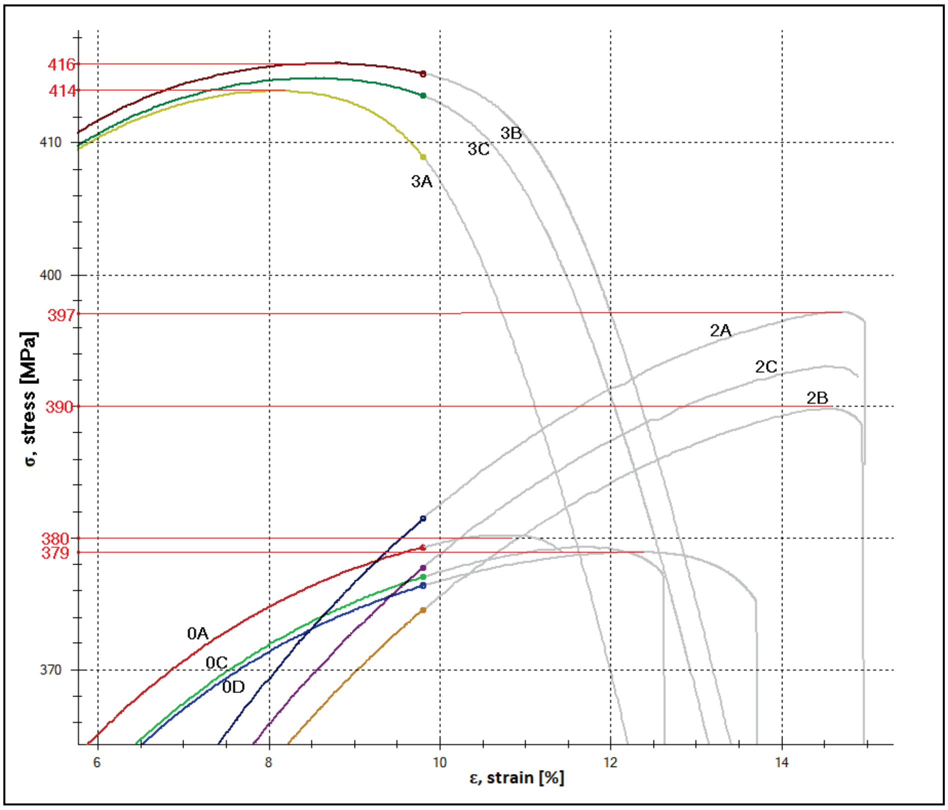

Fig. 5. Comparison of the strength limit R_m for samples aged naturally: 2A, 2B, 2C and artificial: 3A, 3B, 3C and samples of material in the delivery condition: 0A, 0C, 0D

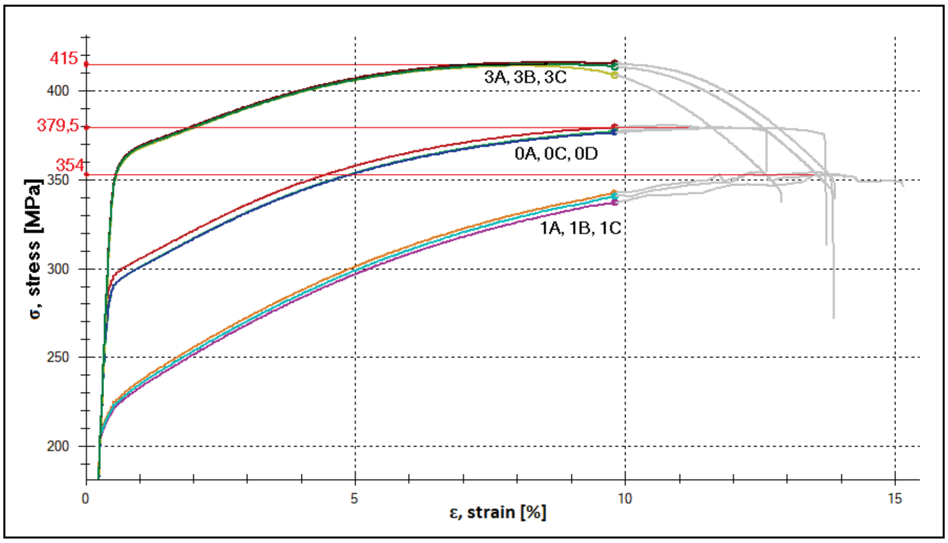

Fig. 6. Samples: 0A, 0C, 0D – delivery condition, samples: 1A, 1B, 1C – intermediate state samples: 3A, 3B, 3C – artificially aged

On Fig. 6 it can be observed that the strength limit R_m for samples subjected to accelerated aging has the highest average values (averages from Tab. 4) of 415 MPa. R_m of samples in the delivery condition has an average value of 379.5 MPa. While samples subjected only to supersaturation, which were then cooled rapidly in water at 20ºC and which were aged for 6 days and were not heated, have R_m values of 354 MPa on average. These are the values lower by about 7% than R_m of the basic material not subjected to any heat treatment. The results show the limits of the strength of the material in the intermediate state after supersaturation and cooling, but without the completed artificial aging process.

In addition, during the tests a significant increase in the plasticity of the material after precipitation strengthening was observed. This is manifested by the increase in elongation at rupture of samples made of naturally aged material for which the average A_{50} value is 14.5% and samples that have been artificially aged, for which the test results revealed an elongation at rupture A_{50} of average 13.1%. The average values A_{50} of the reference material, i.e. the "0" group samples not subjected to precipitation strengthening, were on average 12.1% – Tab. 4. Moreover, for samples aged after supersaturation in an artificial way, the highest values of the measured Z were obtained and amounted to 46.6% on average (Tab. 4). In these samples, the neck was clearly visible (Fig. 7) during the tests.

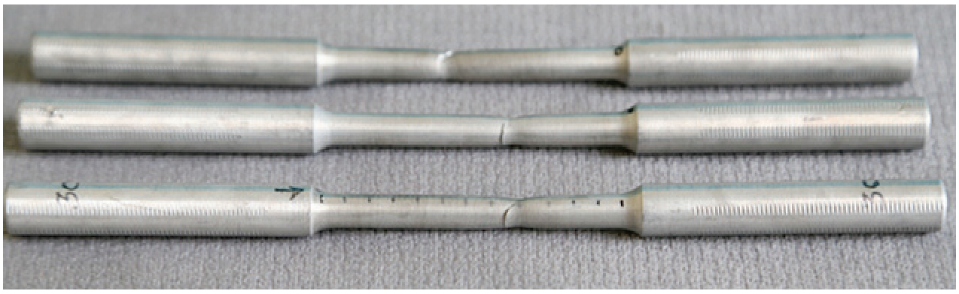

Fig. 7. Samples: 3A, 3B, 3C – artificially aged with a visible neck

In samples made of a material, which after saturation was cooled gently in the air by 20ºC; and then naturally aged no distinct neck is noticed after breaking – Fig. 8.

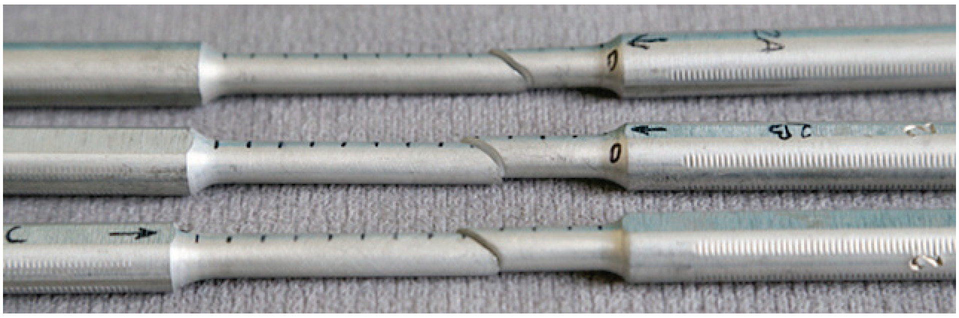

Fig. 8. Samples: 2A, 2B, 3B – naturally aged no visible neck

In samples made of material in the delivery condition, there was also no visible neck – Fig. 9.

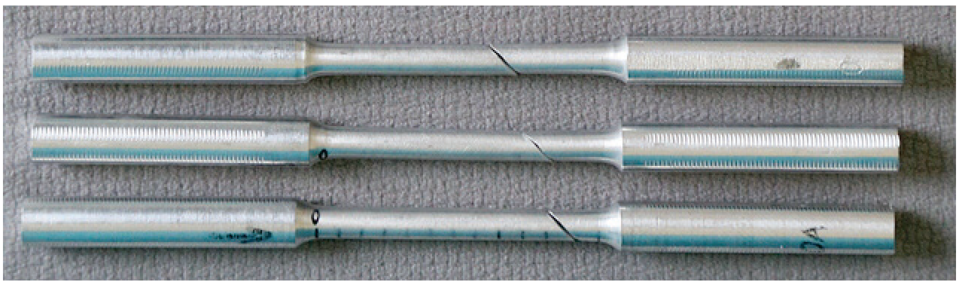

Fig. 9. Samples: 0A, 2C, 3D – alloy AW 7020 F3-type 5 without heat treatment and without visible neck

6. Conclusions

The use of an accelerated process of technological heat treatment of the AW 7020 alloy with rapid cooling in water at ambient temperature after supersaturation and with artificial aging significantly shortens the time to obtain the prepared material relative to the technological heat treatment process with natural cooling after supersaturation and natural aging. This time of process was shortened from 90 days to 7 days.

Precipitation strengthening with rapid cooling in water at ambient temperature and accelerated aging increases the strength properties of the AW 7020 alloy, relative to precipitation, strengthening with air-cooling and natural aging by approximately 5.6%, i.e. occurs an increase in R_m from the average value of 393 MPa to the average value of 415 MPa.

Application of precipitation strengthening with air-cooling and natural aging of this alloy reduces the plasticity of the AW 7020 alloy by around 11% from an average value of A_{50} of 14.5% to an average value of A_{50} of 13.1% relative to precipitation strengthening with rapid cooling in water with ambient temperature and accelerated aging.

Tests for samples made of intermediate material (between technological steps of heat treatment) can better describe phenomena occurring in the material and finally can help improve the technological process.

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