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EFFECTS OF THE HEAT TREATMENT ON THE MECHANICAL PROPERTIES OF THE ALUMINIUM ALLOYS

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Abstract: *This paper aims to investigate the effects of the heat treatment on the mechanical properties in case of EN AW-6060 aluminium alloy. Mechanical characteristics were measured in both the tensile test and the bending test. Although there is standard [1] that indicate the mechanical properties of the aluminium alloy used to manufacture different kinds of profiles, the main purpose of this paper consists in the accuracy comparing of the mechanical properties of the commercial aluminium alloy EN AW-6060 used to manufacture box profiles, that is in T4 state or T6 state depending on the heat treatment. Finally, it is shown that the maximum values* $\pm_{\max}$ *of both the tensile stress and flexural stress are greater with 41.47% and with 75.47% respectively, in case of EN AW 6060 – T6 aluminium alloy than the values recorded in case of EN AW 6060 – T4 aluminium alloy. There are small differences concerning the modulus of elasticity E recorded: 8.13% in case of Young's modulus E determinate in tensile test; 5.34% in case of the modulus of elasticity determinate in the bending test.*
Keywords: *aluminium alloy, tensile test, bending test, heat treatment.*

1. INTRODUCTION

The main purpose of the present paper is to show the effects of the thermal treatment on the mechanical properties of the EN AW 6060 AlMgSi aluminium alloy. The alloy EN AW-6060 AlMgSi is a widely used extrusion alloy. It is recommended for applications such as the following: frame profiles for windows, doors, curtain walls, fences, railings, stairs; frame systems for interior accessories; pneumatic equipment; irrigation pipes; pipes for cooling.
There are British and European standards that give the mechanical properties in case of the extruded rod / bar, tube and profiles made of aluminium alloys [1].
In order to show accuracy the effects of the thermal treatment on the EN AW 6060 AlMgSi aluminium alloy, two kinds of this alloy are tested: EN AW-6060-T4 – aluminium alloy in T4 state; EN AW-6060-T6 – aluminium alloy in T6 state. The T4 state corresponds to the naturally aged to a stable condition while T6 state corresponds to the solution heat treated, quenched and artificially aged [2].

2. MATERIALS AND WORK METHOD

2.1. Materials

In accord with the European Standard SR-EN 573 – 3 / 2010 [3], EN AW 6060 aluminium alloy belongs to the series of 6000 of the aluminium alloys AlMgSi (aluminium – magnesium – silicon). Chemical composition of the aluminium alloy EN AW 6060 is: 0.3÷0.6% Si; 0.1÷0.3% Fe; 0.10% Cu; 0.35÷0.60 % Mg; 0.05 % Cr; 0.15% Zn; 0.10 % Ti; 0.05 % other metallic components so as the sum doesn't exceed 0.15 %; the difference is covered by the aluminium [3]. According to [4] the EN AW 6060 aluminium alloy being in T4 or T6 state are encoded as following: EN AW-6060-T4 or EN AW-6060-T6, respectively.
Tensile specimens (fig. 1, a and c) are manufactured according to European Standard EN ISO 6892-1: 2002 [5]. Flexural specimens (fig. 1, b and d) have 120 mm in length and the width of the rectangular cross-section is 15 mm. The thickness was equal with 3 mm in case of both kinds of specimens.
The both tensile specimens and flexural specimens are cut from the commercial profiles having box cross-section, made of EN AW 6060 aluminium alloy having two different states (T4 and T6) from the heat treatment point of view.

a. b. c. d.

Figure 1: Specimens for testing:
a, b - Tensile / flexural specimens made of aluminium alloy EN AW 6060 – T4; c, d - Tensile / flexural specimens made of aluminium alloy EN AW 6060 – T6

2.2. Work method

In case of the tensile test it was used a tensile machine manufactured by LLOYD Instruments (West Sussex, United Kingdom) whose maximum load capacity is ±50 kN. The speed of loading was 3mm/min according to European Standard EN ISO 6892-1: 2002 [5]. An extensometer was used in order to record the elongation of the specimen. The initial span between the marks in tensile test, was equal with 50 mm [5].
The LR5K Plus machine manufactured by LLOYD Instruments (West Sussex, United Kingdom) was used for the bending test by using the method of the three-point. The maximum load capacity is ±15 kN. The flexural specimen was simply supported at its ends during testing and the span between the supports was equal to 80mm. The crosshead speed was 15 mm/min.

3. RESULTS

The stress-strain $\pm - £$ curves recorded in tensile test are shown in the figure 2. It may be remarked that after the yield point, the $\pm - £$ curves corresponding to EN AW 6060 – T6 aluminium alloy are located above the $\pm - £$ curves corresponding to EN AW 6060 – T4 aluminium alloy. This remark shows that the maximum value of the tensile stress $\pm_{max}$ is greater in case of EN AW 6060 – T6 aluminium alloy with respect to the other one alloy. But the maximum strain $£_{max}$ recorded at maximum force F_{max} is less in case of EN AW 6060 – T6 aluminium alloy with respect to the value recorded in case of the other one alloy.

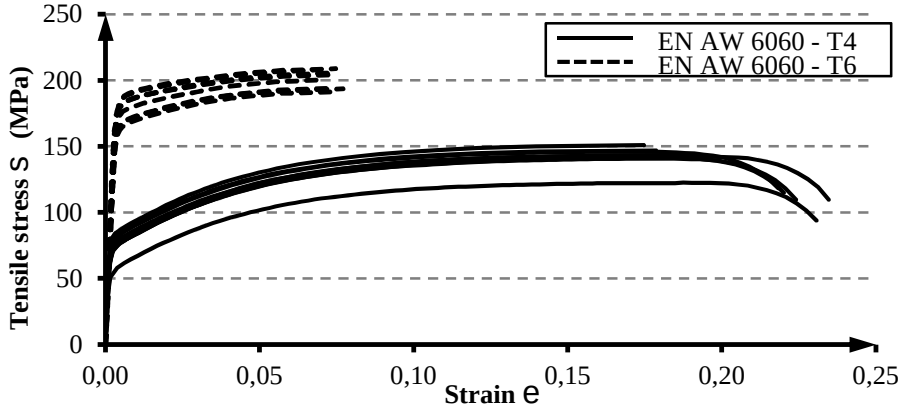

Figure 2: Stress-strain $(\pm - £)$ curve recorded in tensile test

The average values of the mechanical properties recorded in tensile test are shown in the Tables 1 and 2 in case of both alloys tested. The average value of the *Young*'s modulus *E* is greater with 8.13% in case of EN AW 6060

– T4 aluminium alloy $(E = 58302.08MPa)$ than the value recorded in case of EN AW 6060 – T6 aluminium alloy $(E = 53918.88MPa)$. The maximum value of the tensile stress $\pm_{\max}$ is greater with 41.47% in case of EN AW 6060 – T6 $(\pm_{\max} = 200.73MPa)$ than the value recorded in case of EN AW 6060 – T4 $(\pm_{\max} = 141.89\,MPa)$.

The maximum strain $£_{\max}$ recorded at maximum force $F_{\max}$ is greater with 118.55% in case of EN AW 6060 – T4 $(£_{\max} = 0.181555)$ than the value recorded in case of EN AW 6060 – T6 $(£_{\max} = 0.083074)$. This is the reason why the work done to maximum load is with 40.52% greater in case of the EN AW 6060 – T4 aluminium alloy than the value recorded in case of EN AW 6060 – T6 alloy.

Table 1: Mechanical properties determinate in tensile test in case of EN AW 6060 – T4

No. of the tensile specimen	Width (*mm*)	Thickness (mm)	Young's Modulus (*MPa*)	Load at maximum load (*N*)	Stress at maximum load (*MPa*)	Extension at maximum load (*mm*)	Strain at maximum load	Work to maximum load (*N*ℓ*mm*)
1	10.03	3.00	64637.15	3688.81	122.59	9.307	0.186140	30110.30
2	10.02	3.00	49238.73	4253.46	141.50	8.576	0.171511	32164.39
3	10.04	2.98	60051.19	4364.01	145.86	7.961	0.159227	30701.43
4	10.03	2.97	69708.37	4233.04	142.10	9.855	0.197099	37372.48
5	10.03	2.97	68511.38	4196.00	140.86	9.321	0.186418	34841.45
6	10.04	3.00	41589.20	4429.20	147.05	8.751	0.175024	34607.50
7	10.02	2.98	69443.36	4276.93	143.23	9.874	0.197476	37968.98
8	10.02	3.00	35984.27	4308.33	143.32	9.940	0.198800	38553.21
9	10.02	2.96	66625.80	4480.03	151.05	8.561	0.171210	34146.66
10	10.03	2.96	57231.36	4194.89	141.30	8.632	0.172643	31924.46
Average value	10.028	2.98	58302.08	4242.47	141.89	9.078	0.181555	34239.09

Table 2: Mechanical properties determinate in tensile test in case of EN AW 6060 – T6

No. of the tensile specimen	Width (*mm*)	Thickness (mm)	Young's Modulus (*MPa*)	Load at maximum load (*N*)	Stress at maximum load (*MPa*)	Extension at maximum load (*mm*)	Strain at maximum load	Work to maximum load (*N*ℓ*mm*)
1	10.10	3.08	54394.17	6040.18	194.17	3.759	0.075189	21198.39
2	10.12	3.10	50549.08	6419.68	204.63	4.396	0.087926	26734.88
3	10.08	3.06	55698.82	6442.57	208.87	3.842	0.076846	23379.37
4	10.08	3.09	55274.66	6488.78	208.33	4.126	0.082517	25375.94
5	10.08	3.06	52199.15	6192.23	200.75	3.642	0.072848	21064.16
6	10.07	3.07	55148.00	5987.76	193.69	4.650	0.093008	26403.33
7	10.08	3.03	55699.08	6290.69	205.97	4.404	0.088074	26244.02
8	10.04	3.07	58854.75	6329.77	205.36	4.359	0.087180	26191.59
9	10.06	3.09	54328.95	6028.27	193.93	4.280	0.085592	24256.96
10	10.10	3.08	47042.15	5959.63	191.58	4.078	0.081565	22801.10
Average value	10.08	3.07	53918.88	6217.95	200.73	4.154	0.083074	24364.97

The stress-strain $\pm - £$ curves recorded in bending test are shown in the figure 3. The $\pm - £$ curves are graphically shown for the points located at the bottom of the critical cross-section of the flexural specimen (cross-section located at midpoint of the span between supports). It may be observed that the slopes of the elastic portions of $\pm - £$ curves are greater in case of the EN AW 6060 – T6 aluminium alloy. The $\pm - £$ curves corresponding to EN AW 6060 – T6 are located above the curves corresponding to the aluminium alloy that is in T4 state. It follows that both the modulus of elasticity *E* and the maximum flexural stress $\pm_{\max}$ recorded in case of EN AW 6060 – T6 aluminium alloy are greater with respect to the corresponding values recorded in case of EN AW 6060 – T4 aluminium alloy.

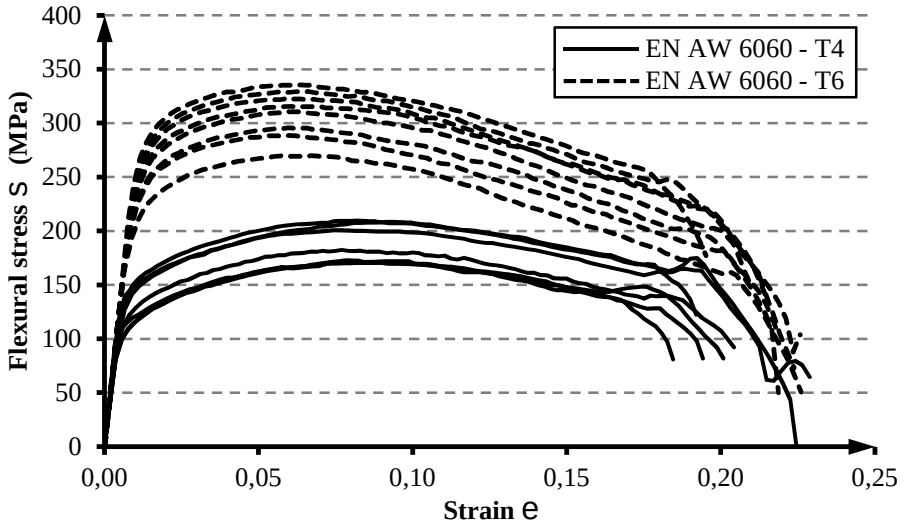

Figure 3: Stress-strain $(\pm - £)$ curve recorded in bending test by using the method of the three points

Table 3: Mechanical properties determinate in bending test in case of EN AW 6060 – T4

No. of the flexural specimen	Width (*mm*)	Thickness (*mm*)	Modulus of elasticity in bending *E* (*MPa*)	Maximum load F_{max} (N)	Maximum bending stress $\pm_{max}$ at maximum load (*MPa*)	Maximum bending strain $£_{max}$ at maximum load	Work *W* to maximum load (*Nmm*)
1	14.99	3.03	24195.22	210.143918	183.24	0.080233	5071.71
2	14.97	3	25094.14	235.429404	209.69	0.080673	5832.21
3	14.98	2.98	28725.84	191.368795	172.63	0.077903	4535.12
4	14.96	3.02	26323.54	228.199728	200.70	0.074979	5227.51
5	14.97	3.03	24379.72	195.545438	170.73	0.091758	5467.38
6	14.97	3	24002.76	193.081071	171.97	0.091631	5430.80
7	15.03	3.01	23939.18	236.133947	208.09	0.091432	6581.14
Average value	14.98	3.01	25237.20	212.84	188.15	0.084087	5449.41

Table 4: Mechanical properties determinate in bending test in case of EN AW 6060 – T6

No. of the flexural specimen	Width (*mm*)	Thickness (*mm*)	Modulus of elasticity in bending *E* (*MPa*)	Maximum load F_{max} (N)	Maximum bending stress $\pm_{max}$ at maximum load (*MPa*)	Maximum bending strain $£_{max}$ at maximum load	Work *W* to maximum load (*Nmm*)
1	14.98	3.11	26281.84	349.03	289.07	0.054529	5531.22
2	15.01	3.12	26515.36	360.01	295.67	0.056681	5915.92
3	15.00	3.11	26303.42	381.58	315.61	0.055917	6164.08
4	15.00	3.11	26522.61	390.39	322.90	0.059204	6770.15
5	15.02	3.11	27389.23	406.20	335.53	0.062158	7459.88
6	14.98	3.11	26502.09	375.13	310.69	0.059510	6522.55
7	15.01	3.11	27355.80	326.97	270.27	0.059547	5715.15
8	14.97	3.11	25801.29	397.63	329.55	0.057807	6680.60
Average value	15.00	3.11	26583.95	373.37	308.66	0.058169	6344.94

The average values of the mechanical properties recorded in tensile test are shown in the Tables 3 and 4 in case of both alloys tested. The average value of the modulus of elasticity *E* is greater with 5.34% in case of EN AW

6060 – T6 aluminium alloy $(E = 26583.95MPa)$ than the value recorded in case of EN AW 6060 – T4 aluminium alloy $(E = 25237.20MPa)$. The maximum value of the tensile stress $\pm_{\max}$ is greater with 75.47% in case of EN AW 6060 – T6 $(\pm_{\max} = 373.37\,MPa)$ than the value recorded in case of EN AW 6060 – T4 $(\pm_{\max} = 212.84\,MPa)$.

The maximum strain $\pounds_{\max}$ recorded at maximum force $F_{\max}$ is greater with 44.56% in case of EN AW 6060 – T4 $(\pounds_{\max} = 0.084087)$ than the value recorded in case of EN AW 6060 – T6 $(\pounds_{\max} = 0.058169)$. But contrary, the work done to maximum load is with 18.43% less in case of the EN AW 6060 – T4 aluminium alloy than the value recorded in case of EN AW 6060 – T6 alloy.

4. CONCLUSION

It is remarked that that the mechanical properties recorded in case of the EN AW 6060 – T6 aluminium alloy are generally greater than the values recorded in case of the EN AW 6060 – T4 aluminium alloy.

The maximum values $\pm_{\max}$ of both the tensile stress and flexural stress are greater with 41.47% and with 75.47% respectively, in case of EN AW 6060 – T6 aluminium alloy than the values recorded in case of EN AW 6060 – T4 aluminium alloy. It follows that the heat treatment corresponding to the T6 state is better than the one corresponding to the T4 state of the EN AW 6060 aluminium alloy tested. Consequently, the profiles made of EN AW 6060 – T6 aluminium alloy whose heat treatment is T6, are recommended to manufacture parts having high strength properties.

It may remark that EN AW 6060 aluminium alloy has large plastic deformations in bending test in case of both kinds of heat treatment (Fig. 3).

A similar remark may be noted in case of EN AW 6060 – T4 in case of the tensile test. The maximum strain $\pounds_{\max}$ recorded at maximum force $F_{\max}$ is more twice greater (with 118.55%) in case of EN AW 6060 – T4 $(\pounds_{\max} = 0.181555)$ than the value recorded in case of EN AW 6060 – T6 $(\pounds_{\max} = 0.083074)$. These remarks lead to the conclusion that EN AW 6060 - T4 aluminium alloy in T4 state is a ductile material.

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