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A Change of Mechanical Properties of the Self-hardening UNIFONT 90 Due to Temperature

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Abstract. UNIFONT 90 is aluminum cast alloy used for engine and vehicle constructions, hydraulic units and mold making without heat treatment (self-hardening alloy). When using this alloy for high-temperature castings, it is necessary to study its structure and mechanical properties depending on the temperature. The contribution describes the effect of temperature in the range from – 196 °C up to + 400 °C on mechanical properties (especially Brinell hardness and bending impact toughness) of the UNIFONT 90. The mechanical properties were measured on samples after cooling and heating for holding 20 minutes at temperature. Fracture surfaces and changes in microstructure of material were evaluated by means of light microscopy and scanning electron microscopy (SEM). The results showed that with increasing temperature, the material was more plastic and making corresponding fracture surface.

Introduction

Aluminum alloys for industry application are divided into two groups. The first are non heat-treatable alloys, achieving their strength by the amount of cold work applied to the alloy. Mechanical properties of non heat-treatable alloys are obtained by hot/cold working mechanisms during their production. The initial strength of these alloys depends on the hardening effect of elements such as Mn, Si, Fe and Mg, individually or in various combinations. The next improvement of the strength can be reached by cold working process, as the aluminum has high ductility and therefore can be easily deformed. The second, heat-treatable or precipitation hardening alloys, reach their strength and other properties following heat treatments. The properties are dependent on heat treatments and age hardening conditions. Significant strengthening can be achieved by heating and cooling, especially with age-hardening process (solution heat treatment, quenching, age hardening by artificial or natural aging). The initial strength of these alloys is also influenced by the addition of alloying elements to pure aluminum [1-6].

Generally, mechanical and microstructural properties of aluminum cast alloys are dependent on the composition; melt treatment conditions, solidification rate, casting process and the applied thermal treatment. By implementing adaptable alloying and process technology, mechanical properties will therefore be radically enhanced, leading to larger application fields of complex cast aluminum components such as safety details [6-9].

The present study is a part of a larger research project, which was conducted to investigate and provide a better understanding temperature effect on the properties of experimental material.

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Experimental material and procedure

The experimental material UNIFONT 90 (AlZn10Si8Mg) was prepared from scrap in foundry UNEKO, s.r.o. Zátor, Ltd. Czech Republic. The experimental bars with dimensions of ø 20 mm and length of 300 mm (blue- Fig. 1) were casted into a sand mold (Fig. 1). The experimental specimens for bending impact test were produced with turning and milling operation without notch (55x10x10 mm) from the experimental bars (Fig. 1). The experimental material belongs to self-hardening alloys that are particularly used when good strength values are required without the need for heat treatment. Self-hardening starts when the castings are removed from the mold and the final mechanical properties are achieved after storage of approximately 7 to 10 days at room temperature. In the process of thin-walled castings, self-hardening completed after 7 days and the thick-walled castings after 10 days. During this time, it is not possible castings processed. Castings of the UNIFONT 90 alloy reach about 50 % after the first day of the casting, and about 80% of the final mechanical properties after the second and third day, which must be taken into account in production conditions. Curing time is reduced by annealing the castings from 100 to 120 °C with the time of holding from 10 to 16 hours depending on the thickness of the cast. Castings made from this alloy are perfectly weldable by standard procedures and can withstand prolonged cyclic loading [3, 10].

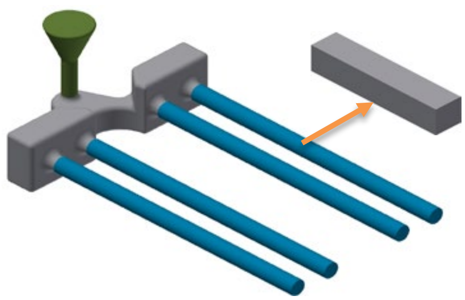

Fig. 1 The scheme of casting module and experimental specimen for impact bending test

The chemical composition of the experimental material was checked out using arc spark spectroscopy, and it is given in Table 1. The experimental material is assigned to aluminum alloys series 7xxxx because of higher amount of Zn, but some international authors include it between Al-Si alloys on behalf of the structure [3, 10].

Table 1 Chemical composition of experimental bars, wt. %

Zn	Si	Cu	Fe	Mn	Mg	Ti	Ni
9.6	8.64	0.005	0.1143	0.181	0.452	0.0622	0.0022
Cr	Hg	Ca	Cd	Bi	P	Sb	Al
0.0014	0.0006	0.0002	0.0001	0.0003	0.0001	0.0007	remainder

The resistance of materials against the formation of fracture depends mainly on temperature, kinds of mechanical stress and geometry of products. The bending impact toughness is a major property which characterizes resistance of materials against the formation of cleavage fracture. Temperature can affect the structure of materials and can lead to changes in properties too. Therefore, Brinell hardness and impact bending toughness were measured. These mechanical properties were measured according to the following standards: STN EN ISO 6506-1 and STN EN 10045-1. Hardness measurement for experimental secondary aluminum alloy was performed using a Brinell hardness (HBW) tester with a load of 250 kp (1kp = 9.81 N), 5 mm diameter ball and a dwell time of 10s. Impact bending toughness (K) was measured on the Charpy hammer with the nominal value of 300J.

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Each property was measured on samples whose temperatures were in the following range: - 196 °C, - 20 °C, + 21 °C - room temperature in time of the test and then elevated temperatures of 50 °C, 100 °C, 150 °C, 200 °C, 250 °C, 300 °C, 350 °C and 400 °C. The higher temperature was reached by the leaving the samples in the electric resistance furnace for holding time of 20 minutes at temperature. The evaluated K and HBW reflect average values of at least six separate specimens.

The samples for metallography observation and assessment of fracture surfaces were prepared from selected specimens (after testing) and were studied using a NEOPHOT 32 light microscope and a VEGA LMU II scanning electron microscope. The metallography samples were prepared by standard metallographic procedures.

Experimental results

Mechanical properties

Multiple types of tests are used for the description of material behavior at elevated and low temperatures. These test are used to monitor the influence of parameters (temperature, time, load, and so on) on mechanical properties. However, the experimental material was also used for the application of the impact bending test for different elevated temperatures. The impact bending test was realized on samples immediately after being removed from the electric furnace for ensuring the endurance of temperature. Fig. 1a shows the measurements results.

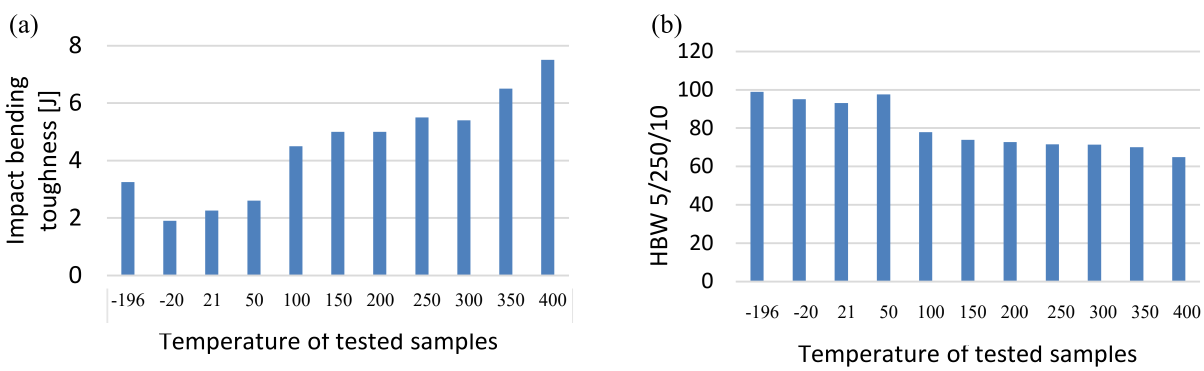

Fig. 1 Results of mechanical properties.
(a) impact bending test; (b) Brinell hardness

The energy required to crack the test samples at room temperature equalled 2.26 J. Then the results show an increase in impact bending toughness with increasing temperature. Two time higher value of energy required for cracking is at 100 °C (4.5 J). The impact bending toughness is similar in the interval of temperature 100 ÷ 300 °C. Three times higher value of energy required for cracking is at 350 °C (6.5 J). Temperature -20 °C leads to the decrease in impact bending toughness in comparison to room temperature, but at the temperature of liquid nitrogen (-196 °C) the value of this toughness increases. The results of the impact bending test show that this material will not have rapid transition from ductile to cleavage fracture.

Hardness was measured on cooled samples after the bending impact test. Fig. 1b shows the results of the Brinell hardness measurements after holding at the temperatures. It can be seen that the measured Brinell hardness decreases with increasing temperature. The interval of – 196 ÷ 50 °C has the highest and similar values. The lowest hardness was measured at 400 °C (64.9 HBW). The results also show similar hardness value in the interval of 100 ÷ 400 °C. The difference between these two

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intervals is about 25.3 %. Based on these results, it is anticipated that strength tensile will be decreasing too [11].

Changes in microstructure

The microstructure of the recycled UNIFONT 90 consists of a primary phase, α-solid solution, a eutectic mixture of α-matrix and spherical Si-phases and various types of intermetallic phases. The α-matrix precipitates from the liquid as the primary phase in the form of dendrites and is nominally comprised of Al and Zn. Al_2CuMg, Mg_2Si, Al (FeMn) Si and ternary eutectic Al-$MgZn_2$-Cu were observed from the intermetallic phases. Small amounts of AlFeMnMgSi and AlFeMnMgNi intermetallic phases were observed in a few areas [10].

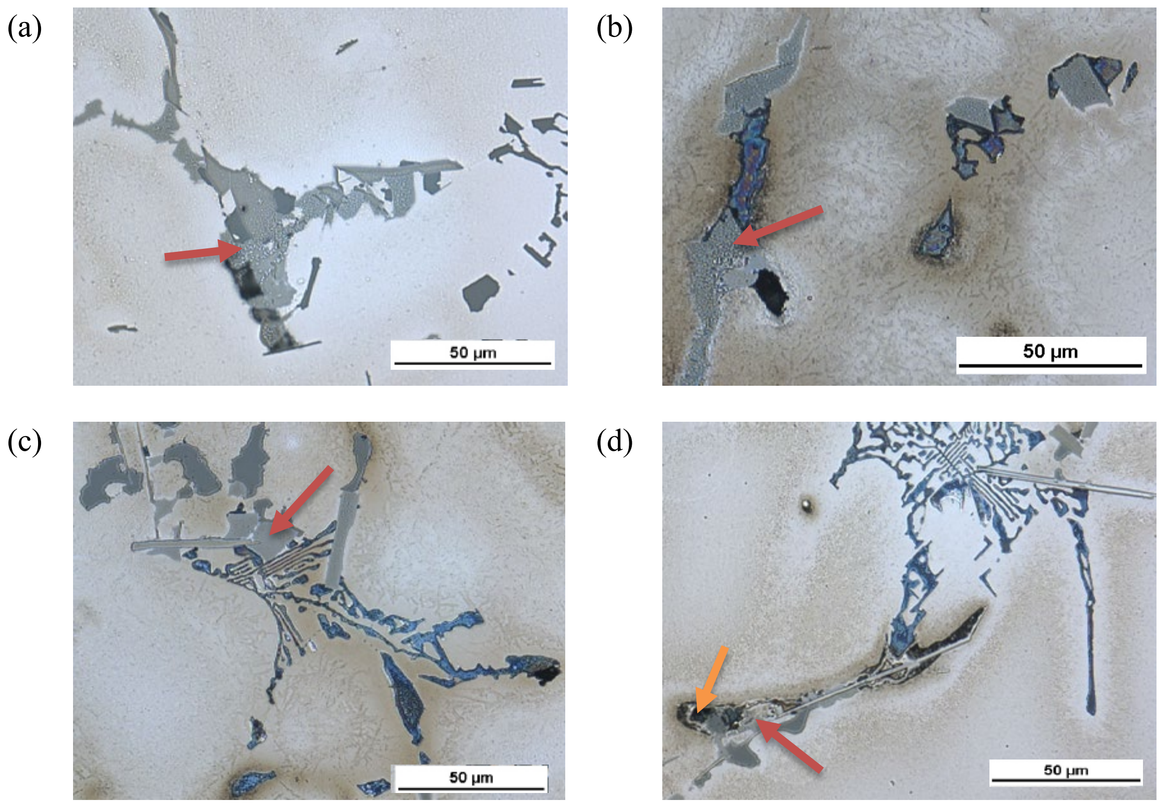

Fig. 2 Morphology changes of Al-$MgZn_2$-Cu, etch. 0.5 % HF.
(a) 21 °° C; (b) 100 °C; (c) 300 °C; (d) 400 °C

The testing temperature has influence on microstructural components. Eutectic silicon particles were coarsened around dendrites of matrix, but no other changes were observed. The metallography observation and quantitative analysis have shown that morphology, size, and distribution of phases Al (FeMn) Si, Mg_2Si and Al_2CuMg were not affected by the increasing temperature. The major changes occurred in the Al-$MgZn_2$-Cu ternary eutectic phases (red arrow in Fig. 2). In the as-cast state (21 °C) has this phase compact shape (Fig. 2a), but with increasing temperature up to 300 °C decreasing size of this phase (Fig. 2b, c). The temperature of 400 °C led to greater changes in morphology of this phase which is fragmented in smaller isolated particles and in a few areas cavities were visible (orange arrow in Fig. 2d). This morphology changes probably relate with the melting point of zinc (419.5 °C) [12, 13].

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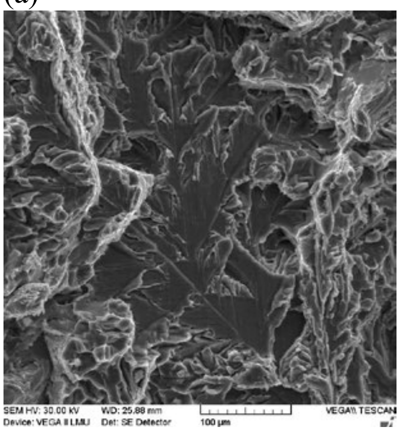
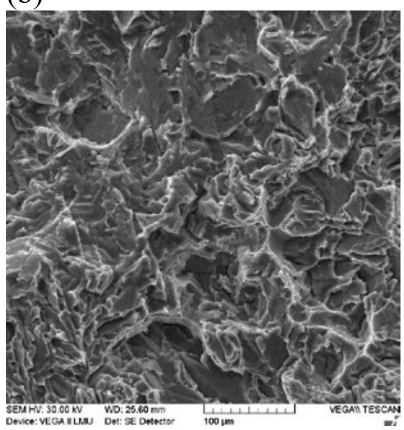
Fracture behavior of experimental material

The fracture surfaces have a mixed character (ductile and cleavage). The character of fracture surfaces at 21 °C and -20 °C is similar (Fig. 3b). The ductile fracture has the same character and ratio. The temperature of -196 °C led to increasing ratio of cleavage fracture thanks to intermetallic phases (Fig. 3a). In a few regions ductile fractures with smaller dimples and plastically transformed matrix (α-phase) ridges were observed in comparison with the state at room temperature. Higher amounts of plastically transformed matrix ridges and grosser dimples were observed in ductile fracture surfaces with the increase of testing temperature (Fig. 3).

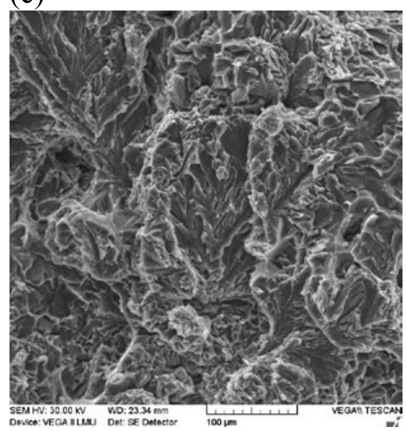
(a)



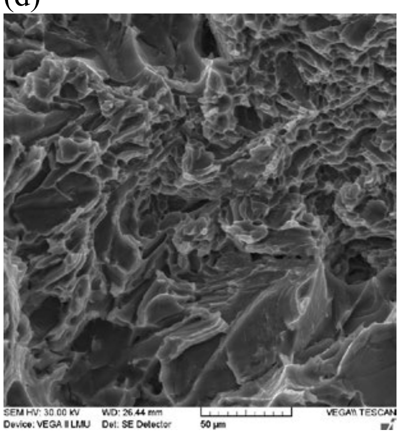
(b)



(c)



(d)



(e)

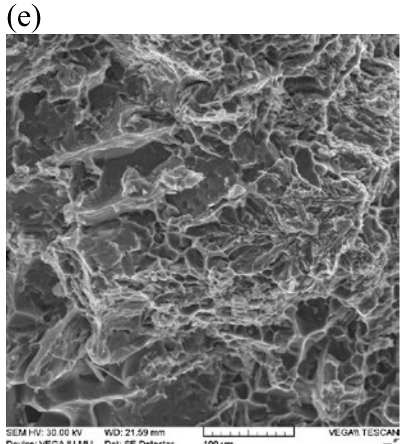


Fig. 3 Changes of fracture surfaces, SEM.
(a) -196 °C;
(b) 21 °C/ -20 °C;
(c); 100 °C
(d) 300 °C;
(e) 400 °C

In general, mixed character cleavage and ductile fracture characters were observed in all surfaces where predominantly there was ductile fracture. Increasing the temperature increases the plasticity of the material on the fracture surfaces, which is reflected by increasing the depth of the ductile dimples and the occurrences of larger amounts of plastically transformed matrix ridges.

Conclusion

Mechanical tests and evaluation of microstructural component changes indicate that different temperature has influence on the increasing impact bending toughness and decreasing hardness. The results show resistance of the material against higher temperature. Mixed fracture (ductile and cleavage) of specimens was observed. Also, the results confirm increasing plasticity with increased temperature. The hardness decreases especially as a result of the changes of ternary eutectic phase's

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morphology during heating at higher temperatures, but the value was about 25.3% lower at higher temperatures.

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