

MEASURING OF STRESS-STRAIN BEHAVIOUR OF STEEL 1.0718 AND ALUMINIUM ALLOY AT DIFFERENT TEMPERATURE RANGE

Prof. M.Sc. Božič S.^{1,3}, Prof. Šircelj D.^{1,2}
Higher vocational school – Postojna, the Slovenia¹
Secondary technical school – Koper, the Slovenia³
Faculty of management – Koper, the Slovenia²

Abstract: A tensile test, also known as tension test, is probably the most fundamental type of mechanical test we can perform on material. The paper determining the tensile properties from stress strain curve by tensile testing of two different materials: steel and aluminium alloy at different range of measuring temperature. Using the values of true stress and true strain the true stress strain curve was plotted. Obtained experimental results will be in our next research compared by a computer program that allows the calculation of certain mechanical properties of both testing materials.

Keywords: STRESS-STRAIN DIAGRAM, STEEL, ALUMINIUM ALLOY, TEMPERATURE

1. Introduction

Tensile test are performed for several reasons. The results of tensile tests are used in selecting materials for engineering applications, during development of new materials and processes can be compared. The strength of a material often is the primary concern. These measures of strength in different condition are used in engineering design. Also of interest is the materials ductility, which is a measure of how much it can be deformed before it fractures.

There are a number of factors that have an effect on the shape of the stress-strain curve. These include strain rate and temperature too. The basic methods and specimens for these tests are similar to room-temperature testing, although the specimen heating, test setup, and material behaviour at higher temperatures do introduce some additional complexities and special issues for hot tensile testing. One of the most important reasons for conducting hot tensile tests is the determination of the hot working characteristics of metallic materials. The proper hot-working temperature must be established to produce high-quality wrought products of complicated geometries.

Experiments of tensile mechanical properties of both testing materials are done on MTS 810 tensile testing machine and the temperature range is changed from 25 °C to 300 °C. Using MTS 810 material testing machine, MTS environmental test chamber, load sensor, ambient temperature extensometer, high temperature extension device, such as thermocouple and digital display. MTS 810 material test system is shown in Figure 1.



Fig. 1 MTS 810 Material test system.

The MTS 810 system is a completely integrated testing package to let you easily obtain information about the mechanical properties of your materials or components. With the wide range of load unit, test control, and test accessory options, it is easily configured to meet your exact testing needs.

The MTS 810 material testing system provides unparalleled capabilities for performing a wide variety of tests on materials, components, and finished goods. The innovative design of the load frame provides reliable service for all types of test and lab environments. Built-in software allows the data collection and treatment to be processed with high speed and accuracy. The bi-axial extensometers obtain Poisson's ratio and R-Value with high accuracy and provide superior performance in linearity, repeatability, hysteresis, low activation force.

The first and most important step in specifying appropriate hot-working practice is to determine suitable hot-working conditions. The major advantage of the hot tensile test is that its stress/strain state simulates the conditions that promote cracking in most industrial metalworking operation. However the tensile test is simple in nature, it may provide misleading information if not properly designed. Parameters, such as the specimen geometry, tension machine characteristics and strain rate and temperature control all influence the results of the tension test.

2. Materials for Testing

The aim of this paper is determination of tensile properties of two different materials: duralumin AlCu4Mg1 and steel with number 1.0718 (SIST EN). The material chemical composition and mechanical properties of both materials are given in Tables 1 and Table 2.

Table 1: Chemical composition of the tested AlCu4Mg1 aluminium alloy and steel 1.0718 [%].

Material	Cu	Mg	Si	Mn	Fe	Ti	Zn	Cr
AlCu4Mg1	4,2	0,75	0,45	0,6	0,7	0,2	0,5	0,1
Material	C	Si	Mn	P	S	Pb		
1.0718	0,14	0,05	1,1	0,11	0,3	0,25		

Table 2: Mechanical properties of the tested AlCu4Mg1 aluminium alloy and steel 1.0718 at 25 °C.

Material	E [N/mm ²]	R _{0.2} [N/mm ²]	R _m [N/mm ²]
AlCu4Mg1	78 000	383	496
1.0718	211 000	529	572

Duralumin AlCu4Mg1 is an aluminum alloy, which, in contrast to pure aluminum, a particularly high strength. Duralumin is an alloy of aluminum, copper, magnesium and manganese. Alloy is a

lightweight, strong and resistant to corrosion. Duralumin is also very hard and is also used by the aerospace industry. AlCu4Mg1 is generally well-machinable. Duralumin consists of about 93 to 95 percent pure aluminum with additions of 3.5 to 5.5 percent copper, and small additions of magnesium, manganese and silicon.

Material – free cutting steel 1.0718 is steel with high percentage of lead and sulphur, which improves machinability without influence on mechanical characteristics. Good machining quality is the requirement for an economical production of turned parts with high precision and excellent surface quality. The material 1.0718 fulfils these characteristics. The possibility to weld, harden and for surface treatments is also guaranteed.

3. Method of test

Tensile test was conducted in normal condition according to DIN EN 10002-1, with boundary conditions according to DIN EN 10002-5. Tests involve straining a test piece in tension, generally to fracture for the purpose of determining one or more of the mechanical properties. Figure 2 shows the shape of the machined test piece. The important part of the specimen is the gage section. The cross-sectional area of the gage section is reduced relative to that of the remainder of the specimen so the deformation and failure will be localized in this region¹.

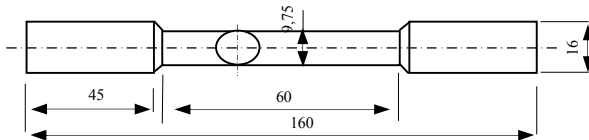


Fig. 2 Tensile specimen.

Typical tensile specimen showing a reduced gage section and enlarged shoulders. To avoid end effects from the shoulders, the length of the transitional region should be at least as great as the diameter, and the total length of the reduced section should be at least for times the diameter¹.

For the purpose of our investigation, the following terms and definitions apply:

Yield strength: when metallic material exhibits a yield phenomenon, stress corresponding to the point reached during the test at which plastic deformation occurs without any increase in the force. Measurement of the stress at which plastic deformation first occurs depends on how accurately strain can be measured. To avoid this problem, the onset of the plasticity is usually described by yield strength, which can be measured with greater reproducibility. It can be found by constructing a straight line parallel to the initial linear portion of the stress-strain curve, but offset by $\epsilon = 0,002$ or $0,2 \%$.

$R_{p0,2}$: stress at which a non-proportional extension is equal to a specific percentage – $0,2 \%$ of the extensometer gauge length. This strain represents a readily measurable deviation from proportionality, and the stress necessary to produce this deviation is the $0,2 \%$ offset yield strength.

Tensile strength (R_m): it is the stress corresponding to the maximum force (F_m). The tensile strength (ultimate strength) is defined as the highest value of engineering stress (patricia Han). Up to the maximum load, the deformation should be uniform along the gage section. With ductile materials, the tensile strength corresponds to the point at which the deformation starts to localize, forming a neck. Less ductile materials fracture before they neck. In this case, the fracture strength is the tensile strength.

Percentage elongation after fracture (A): permanent elongation of the gauge length after fracture, expressed as the percentage of the

original gauge length; A_{10} = percentage elongation of a gauge length of 10 mm.

Modulus of elasticity (E): for most materials, the initial portion of the tensile curve is linear. The slope of this linear region is called the elastic modulus. Modulus of elasticity is the mathematical description of an object or substance's tendency to be deformed elastically when a force is applied to it. The elastic modulus of an object is defined as the slope of its stress-strain curve in the elastic deformation region: $E = (\sigma/\epsilon)$.

4. Experimental results

For our research of mechanical properties we produce five tensile specimens for each material. At the start of the tensile testing we spot welded two thermocouple type K (NiCr/Ni) with the device HotSpot, which is presented in Figure 3.



Fig. 3 HotSpot II thermocouple welder

The HotSpot is portable, capacitive, discharge welding units that allow thermocouple wires to be formed into freestanding beads or directly welded to metal surfaces for temperature sensing. Direct bonding avoids the need for clamps, brackets, straps, and welded wells, and provides a quick, simple, accurate, low cost means, of attaching thermocouple sensing wires on a "when needed", "where needed" basis.

Thermocouple allows measuring temperature during the heating/cooling process. The first thermocouple was welded to the center of the tensile specimen. Figure 4 show a specimen of aluminum alloy, which has a central spot welded thermocouple type K. The tensile specimen during the installation of thermocouple embedded in the corresponding fixture.



Fig. 4 Aluminium alloy tensile specimen with a spot welded thermocouple in the middle of the sample.

Tensile specimen welded with two thermocouples was then placed in the measurement system MTS 810. With induction heating process we follow the course of temperature in the two-point embedded thermocouples. When the temperature in the middle of the tensile specimen was 300 ° C we recorded the temperature at the edge of the tube, which later serve as reference for carrying out tensile test of an alloy AlCu4Mg1. The same procedure for both materials was performed both at 300 ° C and 100 ° C. Figure 5 shows a tube of aluminum alloy AlCu4Mg1, which is supported by both jaws of the measuring system MTS 810, and positioning of the two thermocouples.



Fig. 5 Aluminum alloy AlCu4Mg1 tensile specimen with a two spot welded thermocouple.

The research was continued by the tensile testing of both materials at three different temperature 25 ° C, 100 ° C and at a temperature of 300 ° C. Tensile test was carried out in accordance with basic standards for the measurement of characteristics in a tensile test EN 10002-1 (Part 1: Method of test at ambient temperature). At higher temperatures, the tensile test conducted in accordance with standard EN 10002-5 (tensile testing at elevated temperature).

During tensile testing we measure elongation with axial extensometer which measure strain when the load is applied. This is important for metals and similar materials that exhibit high stiffness.

Material test system MTS 810 has automatic range selection and will capture data even if the range initially selected is too small. Range of the deformation rate 0,5 mm/min is selected using past experience and specification data for both materials.

Table 3 and Table 4 present the data results of measurements of tensile specimens of aluminum alloy AlCu4Mg1 and steel 1.0718 in three different temperature.

Table 3: Results of aluminium alloy AlCu4Mg1 tensile specimens

Properties	Temperature °C		
	25	100	300
$R_{0,2}$ [N/mm ²]	383	354	110
R_m [N/mm ²]	496	444	113
E [N/mm ²]	78000	75000	55000
A_{10} (%)	13,4	13,4	23,1

Table 4: Results of steel 1.0718 tensile specimens

Properties	Temperature °C		
	25	100	300
$R_{0,2}$ [N/mm ²]	529	516	444
R_m [N/mm ²]	572	568	540
E [N/mm ²]	211000	216000	182000
A_{10} (%)	12,8	13,1	20,0

Fig 6 shows the stress-strain curve of tensile specimen of aluminum alloy AlCu4Mg1 at three different temperatures.

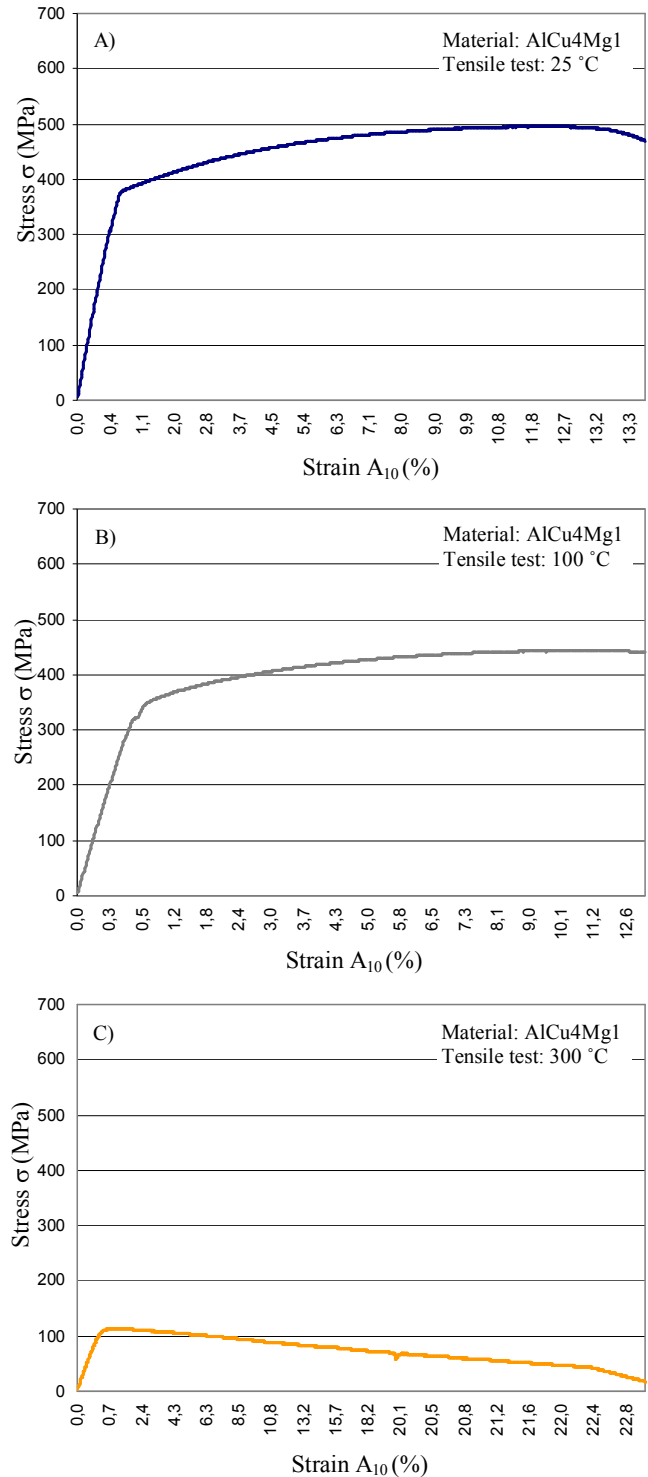


Fig. 6 Stress-strain curves for aluminium alloy AlCu4Mg1 at three different temperature 25 °C (A); 100 °C (B); 300 °C (C);

The diagrams in Figure 6 show the relationship between stress σ (MPa) and elongation A_{10} (%) or mechanical properties as a function of temperature for aluminum alloy AlCu4Mg1. Fig 6A shows the tensile test at 25 °C, the stress-strain diagram in figure 6B shows a tensile test at temperatures of 100 °C, and figure 6C shows the tensile test at temperatures of 300 °C.

Yield strength at room temperature is 383 N/mm², at 100 °C 354 N/mm², at 300 °C yield strength reaches only 110 N/mm². The yield strength decrease as the temperature increases. Yield strength at 100 °C decrease for 7,6 % and yield strength at 300 °C decrease for 71,2 % relative to the yield strength at room temperature. Tensile strength at room temperature is 496 N/mm², at 100 °C 444N/mm², at 300 °C tensile strength reaches only 113 N/mm².

The table 5 shows the tensile test data – yield strength $R_{p0,2}$ and tensile strength R_m for aluminium alloy AlCu4Mg1 as a function of temperature.

Table 5: Percentage changes of mechanical properties for alloy AlCu4Mg1

Properties	25 °C	100 °C	300 °C
$R_{0,2}$ [N/mm ²]	383	354	110
Percentage changes with respect to room temperature	/	7,6	71,2
R_m [N/mm ²]	496	444	113
Percentage changes with respect to room temperature	/	10,5	77,2

Fig 7 show the stress-strain curve of tensile specimen of steel 1.0718 at three different temperatures.

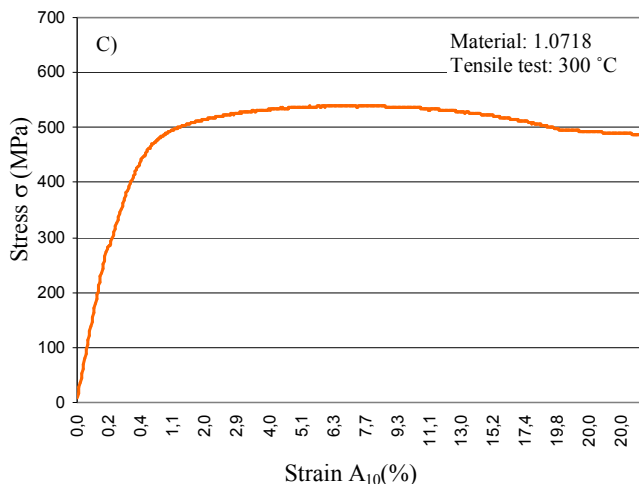
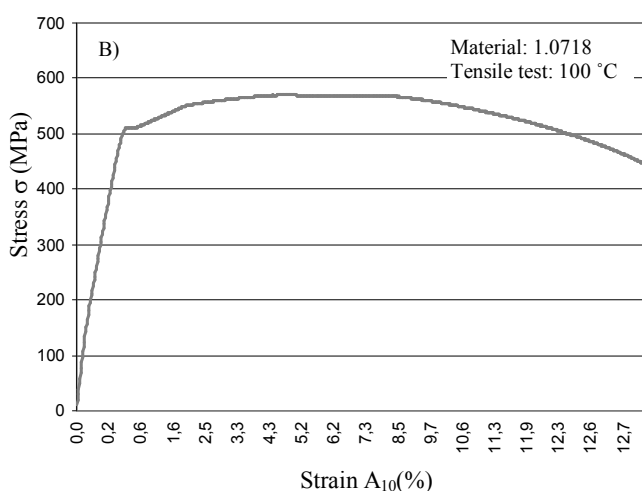
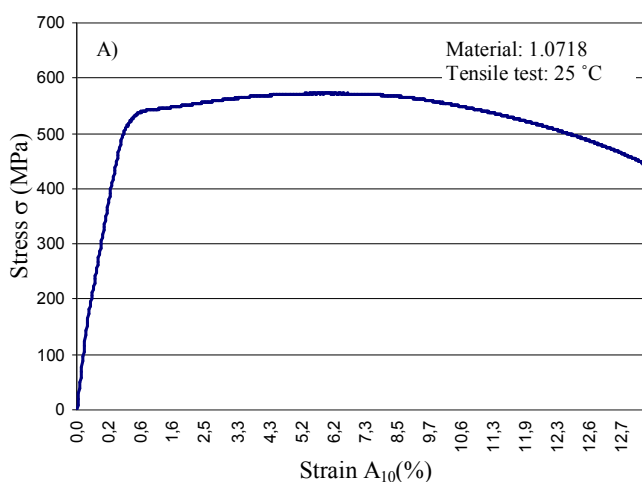


Fig. 7 Stress-strain curves for steel 1.0718 at three different temperature 25 °C (A); 100 °C (B); 300 °C (C);

The diagrams in Figure 7 show the relationship between stress σ (MPa) and elongation A_{10} (%) or mechanical properties as a function of temperature for steel 1.0718. Fig 7A shows the tensile test at 25 °C, the stress-strain diagram in figure 7B shows a tensile test at temperatures of 100 °C, and figure 7C shows the tensile test at temperatures of 300 °C.

Yield strength at room temperature is 529 N/mm², at 100 °C 516 N/mm², at 300 °C yield strength reaches only 444 N/mm². The yield strength decrease as the temperature increases. Yield strength at 100 °C decrease for 2,45 % and yield strength at 300 °C decrease for 16 % relative to the yield strength at room temperature. Tensile strength at room temperature is 572 N/mm², at 100 °C 568 N/mm², at 300 °C tensile strength reaches only 540 N/mm².

The table 6 shows the tensile test data – yield strength $R_{p0,2}$ and tensile strength R_m for steel 1.0718 as a function of temperature.

Table 6: Percentage changes of mechanical properties for steel 1.0718

Properties	25 °C	100 °C	300 °C
$R_{0,2}$ [N/mm ²]	529	516	444
Percentage changes with respect to room temperature	/	2,45	16
R_m [N/mm ²]	572	568	540
Percentage changes with respect to room temperature	/	0,7	5,6

By increasing the temperature tensile test, tensile strength drop for steel 1.0718 is not so significantly. At a temperature of 300 °C tensile strength drops to only 5.6 % of the value achieved at room temperature.

6. Conclusions

The tensile test of both materials, aluminium alloy AlCu4Mg1 and steel 1.0718 provides basic information concerning the response to mechanical loading. Test temperature and strain rates are controlled because of the effects of these variables on the metallurgical response of the specimen.

The yield strength and tensile strength decrease as the temperature increases. These dependencies result from a combination of several metallurgical effects⁴.

The differences of mechanical properties of steel 1.0718 (yield strength $R_{p0,2}$ and the tensile strength R_m) at temperature 25 °C and 100 °C are very small. Mechanical parts, made from steel 1.0718 will remain unchanged mechanical properties at higher working temperature up to 100 °C.

The steel 1.0718 (EN 10087: 11SMnPb30) is marked by a good machinability on machine tools and by an easy fragmentation of chips. In order to further improve its machinability, this steel grade can be supplied upon request with Te (tellurium) and Bi (bismuth)

addition. Due to the high sulphur and phosphorus content free-cutting steels not destined to heat treatment and are not generally recommended for welding.

According to published data in the literature where the ranges for $R_{p0,2}$ and the tensile strength R_m are very large (for example - R_m of 380 N/mm² to 570 N/mm², in some literatures, even from 370 N/mm² to 710 N/mm²), the measuring of mechanical properties at different temperature is very useful. The designers can use yield strength $R_{p0,2}$ and the tensile strength R_m for optimal setting permissible stresses and hence the optimal dimensions of the product.

Steel 1.0718 is not intended for machine parts that operate at 300 °C, therefore the information on mechanical properties is not so important, other than information that the strength at that temperature has dropped noticeably.

Aluminium alloy AlCu4Mg 1 is alloy of aluminum (over 90 %) with copper (4,2 %), magnesium (0,75 %), and manganese (0,6 %). Before a final heat treatment the alloy is ductile and malleable. After heat treatment a reaction between the aluminum and magnesium produces increased hardness and tensile strength. Because of its lightness and other desirable physical properties, duralumin is widely used in the aircraft industry³.

AlCu4Mg1 can be used only to a temperature of 120 °C. Higher temperature caused softening and intergranular corrosion of the alloy and hence a drastic drop of mechanical properties, as is evident from the results of our tensile test. According to published data in the literature where the ranges for $R_{p0,2}$ and the tensile strength R_m are very large (for example - R_m of 395 N/mm² to 495 N/mm²), the measuring of mechanical properties at different temperature is very important.

It is interesting that our test specimen of duralumin AlCu4Mg 1 has the upper value of mechanical properties which further confirms that it is necessary to optimize the design with testing of the mechanical properties and using proven materials.

Yield strength and tensile strength at elevated temperature of 300 °C is significantly reduced. The scope of materials at these temperatures is limited and designers must specify the intended applications.

In our future research we want to confirm our data with program JMatPro. JMatPro is a cross-platform program which calculates a wide range of materials properties for alloys and is particularly aimed at multi-components alloys used in industrial practice.

7. Literature

1. Davis, J.R., *Tensile testing (second edition)*. ASM international, Material park, Ohio, 2004.
2. Han, P., *Tensile testing*. ASM international. Material park, Ohio, 1996.
3. Dwight, J., *Aluminium Design and Construction*. Routledge, 1999.
4. Baron, H.G., Stress-Strain curves of some metals and alloys at low temperature and high rates of strain, J. Iron Steel Inst., Vol 182, 1956.