

The Mechanical Properties of 3D Printed CuZn28 Brass Specimens with Different Orientations

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Abstract. In this paper, the properties of CuZn28 brass raw material were presented. The 3D printed metal specimens are made from this material with different orientations. Their mechanical properties (tensile strength, yield strength) and elongation were investigated according to MSZ EN 6892-1: 2012 standard. The strength of the different printing directions is analyzed and it is determined which printing direction is the most favourable. Finally, the effect of the different printing directions upon the structure of the material is studied.

Introduction

At the present day, 3D printing is already widespread in the industry, and we can produce not only metal models but also metal parts. Three-dimensional object can be manufactured using laser melting from metal powders. With 3D metal printing technology, external and internal free surfaces or so-called "impossible design" shapes can be created but they cannot be produced using traditional manufacturing technologies. The new 3D metal printing technology is better than the traditional 3D printing, as the parts, which are manufactured by this technology, are not only models, but also ready for use. Component are produced by new technology that can be directly incorporated into machines after machining.

The orientation of 3D printing greatly influences the mechanical properties of parts created by laser sintering technology. According to the technical literature [4], the mechanical properties of 3D printed part vary in different directions, so, the cause of anisotropy can be attributed to the solidification process [6]. The difference depends on the direction of the particle growth. The particles typically start to grow from the colder side to the warmer side. During laser sintering, the colder side is the bottom of the melt, the material there is already melted and solidified. The heat conduction of cooled solid material is much higher than the heat conduction of powder [8]. The top of the melt pool is heated by the laser beam, and the gas atmosphere adjacent to the surface has a much weaker heat transfer ability than a solid metal. Material represents orthotropic behaviour due to the different temperature zones in the build area [3, 7]. The mechanical properties of 3D printed metal materials depend on the building direction [1], they are not identical within the printed solid. This property is further

influenced by printing in different directions in the machine's workspace. Rehme et al. [2] investigated the directional dependence of 3D printed metal specimens. 145 repetitions were performed.

The specimens, which made from X2CrNiMo17-12-2 (1.4404) stainless steel for every 15° angle in shape of hemisphere. The strength of the raw material was measured. The average yield strength of 3D printed specimens were 525 MPa and 486 MPa in the x-y and z plane, respectively. A similar deviation was observed for the tensile strength, the tensile strength of the 3D printed specimens in the x-y plane was 605 MPa, while the tensile strength of the printed specimens in the z plane was 543 MPa. The maximum value, 618 MPa, was measured in case of those specimens, which make an angle of 15° with x-y plane. The minimum value, 540 MPa, was measured in case of those specimens, which make an angle of 75° with x-y plane. The maximum and minimum of elongation at breaks are 29,7% and 10,5% in case of specimens with 15° and 75°, respectively. Smaller differences are caused in the mechanical properties by the rotation in the x-y plane. The specimens created into x direction are weaker than the specimens created into y direction. However, the reason for this is due to the optical system, the beam energy in the x direction was 1.5 times higher than the y direction because of the inaccuracy of collimator lens, so components, which created with higher energy density in the y direction had higher strength. Dependence on the direction can therefore be influenced by beam quality and optical system. However, the building direction does not affect the modulus of elasticity, since the modulus of elasticity does not depend on the crystal structure, but depends on the microstructure [2]. The scanning strategy means the lighting method of the layers. It has a great influence on the thermal conductivity, the structure of material and the growth direction of the particles during the solidification. The choice of strategy therefore influences not only the production time, but also the quality of the product both in terms of mechanical and roughness. One of the features of the component created by the additive manufacturing technology is the anisotropy.

Method

The change of mechanical properties of the copper alloy powder (CuZn20) available on the market have been investigated due to the modification of manufacturing parameters. The machine settings have been varied to achieve the highest strength. It was a question of whether the manufacturer's strength values could be produced with the best technological parameters.

Factors influencing the strength of the finished product:

- The moisture content of the raw material.
- Lighting and sintering strategy.
- Laser energy.
- Backfill.
- Printing orientation.

The building directions affect not only the print time, but also the mechanical properties of the workpiece as well as the amount of support material and the surface quality of the workpiece. According to our experience, it is worth inserting the workpiece into the workspace of 3D printer that its flat surfaces form 45° angle to the machine table. In this orientation, the flat surfaces will be best.

The notable 3D printing directions of the machine are studied. Various parameters were measured by tensile testing machine according to MSZ EN 6892-1:2012 standard. Measurements were repeated five times in all cases. For the measurements, a Zwick Roel Z100 universal tensile test machine was used.

The specimens were produced by Thinkspace CL/CTS2 Pro 3D printer. The build size of the machine: 250 x 250 x 280 mm (x, y, z). The different printing arrangements are illustrated in Figure 1.

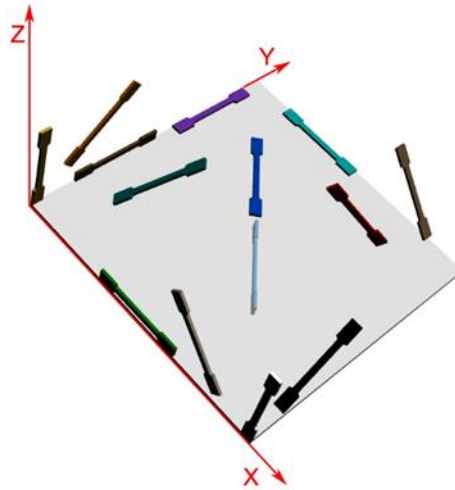


Figure 1. Specimens in the build area of 3D printer

The specimens are labelled as follows: the first two characters represent the plane of the print and the third character indicates the building direction. For example, the xy_x marking means that the specimen was created in the plane of the machine and the powder was spread parallel to the x axis.

Material

CuZn28 is a solid solution strengthened copper alloy containing 28% zinc (brass). The alloy has very good cold forming properties and can be brazed and soldered, welding processes need to be executed with care, due to the high zinc content. As the zinc content increases, the strength improves, yet the conductivity and ductility are reduced and the alloy gets more susceptible to stress corrosion cracking if exposed to an ammonia atmosphere, compared to pure copper. If exposed to an ammonia atmosphere, CuZn28 should be stress relieved. Due to the raised zinc content the alloy has economic advantages. Fields of application are metal ware and deep drawing parts, automotive, heat exchangers, connectors, chains, coolers and components of electrical and mechanical engineering.

Cu	Fe	Pb	Zn	Al	Ni	Sn
[%]	[%]	[%]	[%]	[%]	[%]	[%]
71-73	0.05 max	0.05 max	rem	0.02 max	0.3 max	0.1 max

Table 1. The chemical composition of the measured copper alloy.

This alloy is in accordance with RoHS 2002/96/CE for electric & electronic components and 2002/53/CE for the automotive industry. Mechanical properties of these materials are shown in Table 2.

	Tensile Strength	Yield Strength	Elongation A ₅₀	Hardness HV	Bend ratio 90° [r]	
	[MPa]	[MPa]	[%]	[-]	GW	BW
R270	270-350	≤ 160	≥ 40	55-90	0	0
R350	350-430	≥ 170	≥ 21	95-125	0	0
R410	410-490	≥ 260	≥ 9	120-155	0	0
R480	480-560	≥ 430	≥ 4	150-180	0	1
R550	550-640	≥ 530	≥ 2	170-200	0.5	2
R630	≥ 630	≥ 610	-	≥190	1	3

Table 2. The mechanical properties

Results

CuZn28 specimens in different orientations are made by 3D printing. 5 pieces of each orientation specimen are printed. The results of the measured strength parameters can be seen in Table 3. The yield strength (Rp0,2), the ultimate tensile strength (Rm) and the modulus of elasticity (E) have been determined. 70 pieces of specimens made from CuZn28 were broken. The stress-strain diagram of a specimen can be seen in Figure 2. According to the diagram, the material is capable of a significant deformation, in this case 23%. Furthermore, the decrease of force is not visible during the loading, despite the large deformation, the material has behaved brittle.

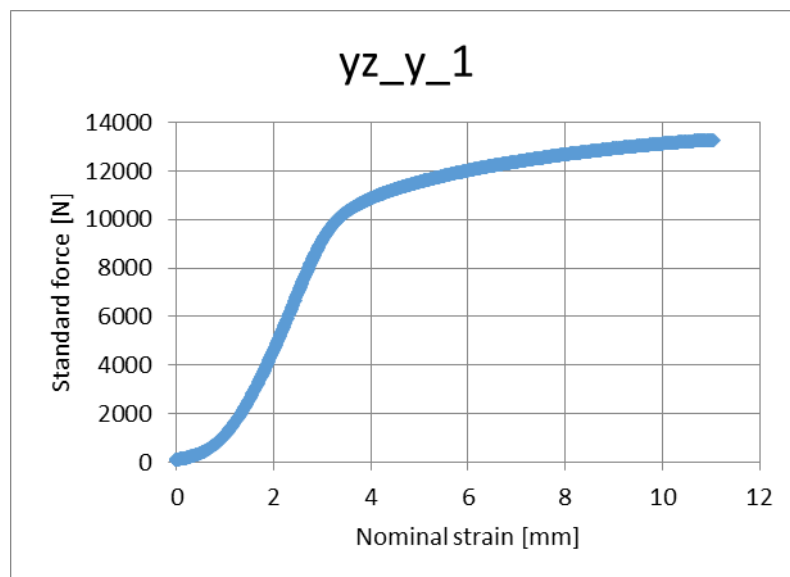


Figure 2. The stress-strain diagram

The tensile tests were carried out at room temperature. Measurements were made by MSZ EN 6892-1:2012 standard. In each measurement direction, 5 pieces of specimen were tested.

	Direction	R _{p0,2} [Mpa]	R _m [Mpa]	E [GPa]
1	xy_x	433	577	12,3
2	xy_y	423	573	11,9
3	xy_45	408	498	25,5
4	xz_x	412	502	12,6
5	xz_z	431	505	12,8
6	xz_45	423	474	28,9
7	yz_y	411	524	12,2
8	yz_z	403	567	12,5
9	yz_45	414	516	26,7
10	xyz_45	421	553	45,1

Table 3. Results

Based on the results, the values of the strength parameters do not depend on the direction of printing. The average yield strength is (Rp0.2) 417 MPa. The average tensile strength is (Rm) 529 MPa. The modulus of elasticity is largely dependent on the orientation of the printing in this case. The modulus of elasticity can be up to 3.5 times the same strength parameter, but the highest value is only 45 GPa.

Summary

This study focuses on the strength properties of the CuZn28 material in terms of the printing orientation. Specimens were made in various notable directions of the machine workspace by 3D printing. According to the technical literature, the 3D printed specimens, which made in different orientations, are anisotropic. Compared to the literature data, it is concluded that the strength parameters do not depend on the printing orientation in case of brass. The strength parameters of 3D printed brass correspond to the brass produced by conventional technology. Based on our measured data, it is considered that the highest modulus of elasticity of 3D printed brass is half of the material produced by traditional technology.

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