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A Concept to Carry Out a Torsion Test on Components Made of 20CrNiMo2-2 Steel Using Additive Techniques

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Abstract. In recent years, additive manufacturing (AM) technologies, have been one of the fastest developing methods of production of various components. As far as building material is concerned, they allow for using not only polymers, but also composites or metals. Products fabricated using said technologies are used in various areas of industries, for instance in medicine, architecture, entertainment, and in particular in the construction of parts and components of machinery and equipment. To recognize and determine the products' strength properties in a more comprehensive manner, 3D printing products used in mechanical applications are subject to various tests, e.g. static tensile test. This paper contains research about static torsion test on cylindrical samples made of high grade 20CrNiMo2-2 steel using the selective laser melting (SLM).

Such an approach allowed to observe the material behaviour and to determine specific values of strength properties, such as the maximum tangential stresses in the material and bulk modulus of elasticity (shear modulus). The determination of such parameters allowed to compare them with the results of the tests carried out on components manufactured using other methods (e.g. a cold drawn solid bar sample).
Keywords: additive manufacturing technologies, 3D printing, static tensile test, static torsion test

1. APPLICATION OF ADDITIVE TECHNIQUES

Current technological development and the severe operating conditions of machinery and equipment are prompting research into new innovative manufacturing techniques to meet the above requirements. A direction experiencing dynamic growth covers additive manufacturing technologies, commonly referred as 3D printing. Over recent years, the use of this technology could be noticed not only in mechanical engineering, but also in many other areas of life (medicine, architecture and entertainment). Example applications are presented in Fig. 1.

Fig. 1. Objects manufactured using 3D printing [1]

Additive manufacturing (AM) of relatively small machineries parts and equipment with complex geometry, numerous indicates advantages in comparison to other manufacturing techniques. These advantages include:

- lower material consumption and possible material reuse (in the SLM method, the laser melts only the amount of powder essential to build one of the layers of an object, and the remaining powder after sieving can be used in the subsequent process);
- possibility to manufacture complex geometries (with the use of support structures, and enclosed voids);
- possibility to manufacture components with complex internal structures, e.g. honeycomb structure (reduced material mass with the same strength properties).

2. STATIC TENSILE TEST OF THE PRINTED OBJECTS

In order to assess the capacity of AM to machinery and equipment, tests were carried out to determine the properties of the manufactured components. Due to the character of loads and periodicity of their occurrence, the strength properties of the manufactured components played the most important role. One of the tests that allowed these parameters to be determined in this scope was the static tension test. In the field of strength tests, it is one of the most popular topics discussed in numerous publications. A sample for this test is presented in Fig. 2.

Fig. 2. A cylindrical sample mounted in a universal testing machine's clamp [2]

On completion of such a test for a specific series of samples, the relationship between the stresses in the material and sample elongation was obtained. On this basis, it is possible to determine key material properties, such as the yield point and ultimate strength. An example graph is presented in Fig. 3.

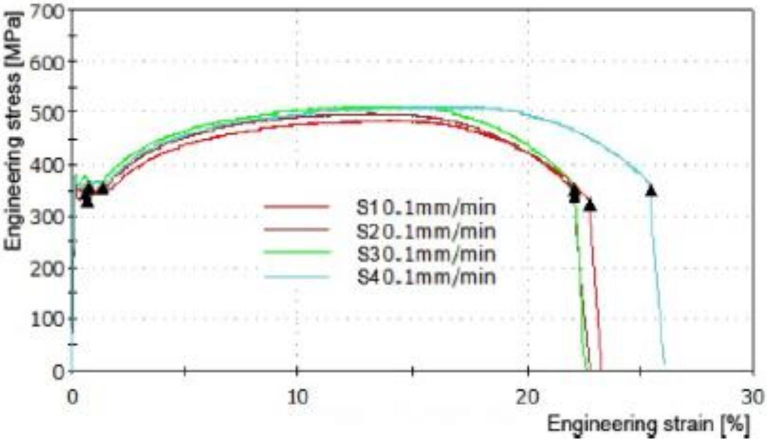

Fig. 3. Relationship between sample stress and elongation [2]

3. A CONCEPT OF STATIC TORSION TEST

The needs and strict requirements relating to the components of modern machinery, determine usage of new manufacturing technologies to optimize their production process. To do this, a more comprehensive examination of the AM component properties is essential. Apart from the static tensile test, an example test highlighting key strength properties of a material is the static torsion test. Analysing topics brought up in scientific publications, it can be noticed that the performance of torsion tests on materials manufactured using AM is rarely discussed. To complement this field, it appears that the test discussed will be an appropriate step toward more comprehensive recognition of components manufactured using additive technologies. The test under consideration is carried out in three stages.

3.1. Creating a 3D model in CAD

Sample geometry was designed using SolidWorks 3D software. Its shape and dependencies between dimensions comply with ISO 18338:2015 [3] and are presented in Fig. 4.

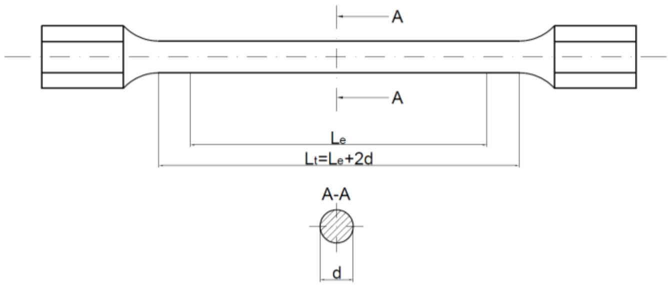

Fig. 4. Dependencies between key sample dimensions [3]

According to the above mentioned standard, the value of L_e is 50 or 100 mm, whereas d, which is the diameter of the tested section of the sample, is 10 mm. In other cases, sample dimensions are selected depending on the value of the set load. It should be noted, however, that L_t is the sum of L_e and two values of the diameter [3]. The fillet radius at the transition from the cylindrical section to the mounting section is not a vital aspect. It is important to remember that its value should be adjusted to avoid the occurrence of an undesirable notch. In this case, the front surface of the mounting section is a regular hexagon, which ensures an uniform transfer of load from the universal testing machine's clamp to the sample.

3.2. Manufacturing of appropriate samples using SLM

Samples are manufactured with a printer presented in Fig. 5 using selective laser melting of metal powder.

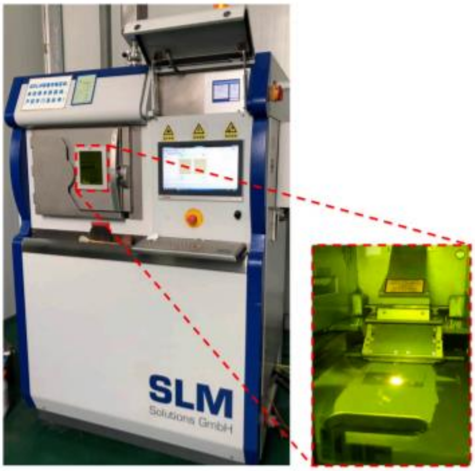

Fig. 5. SLM 125 HL AM system [4]

A file generated and converted in advance using design-supporting tools is read by the printer and the latter initiates the manufacturing process. Prior to this process, excess material is kept (by modifying a 3D model) to perform finishing. To remove surface imperfections after printing (reduce roughness), reduce axial run-out, and provide the sample with accurate dimensions, finishing is used.

3.3. Performance of static torsion test

The static torsion test is carried out using a universal testing machine presented in Fig. 6.

Fig. 6. Instron 8802 universal testing machine. [own materials]

Mount the sample in the previously set clamps presented in Fig. 8.

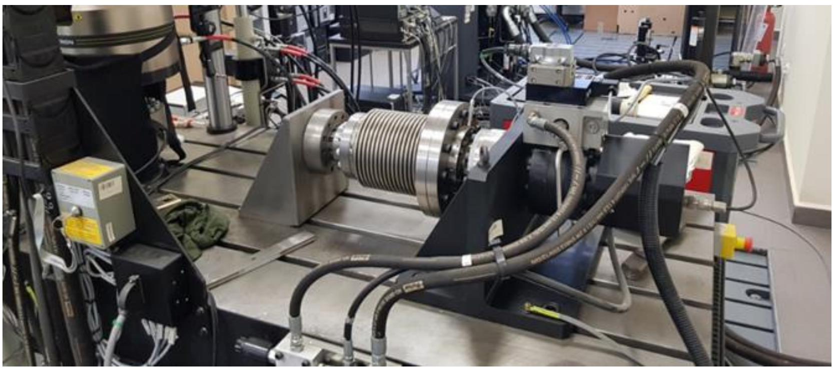

Fig. 7. Torsion test stand. [own materials]

Using the Instron 8802 software, set the appropriate torsion strength tests parameters (torque, rotational speed and maximum angle of rotation). When the values are set, the process is initiated. The machine's sensors record key test parameters on an ongoing basis.

4. ANALYSIS OF TEST RESULTS AND CONCLUSIONS

On the basis of the series of tests, are analyzed the values of key parameters from subsequent tests by comparing them. Use the equation (1) to determine the maximum tangential stresses [5] in the component subject to torsion. Then compare them with the results of torsion strength tests of samples made of the same material, but using a conventional method (e.g. a cold drawn or rolled solid bar sample).

$$\tau_{max} = \frac{M_s}{W_o} \tag{1}$$

where:

τ_{max} – maximum tangential stress;

M_s – torque at which the sample failed;

W_o – torsional section modulus, $W_o = (\pi d^3)/16$.

Additionally, to improve the analysis of the properties of the tested material, measure the α angle to determine the shear modulus (bulk modulus of elasticity) [5]. To do this, use the following equation (2).

$$G = \frac{M_s * l}{I_o * \varphi} \tag{2}$$

where:

G – shear modulus;

M_s – torque at which the sample failed;

l – rod (sample) length;

φ – angle of rotation of the sample;

I_o – polar moment of inertia; $I_o = (\pi d^4)/32$.

Using the tests and observations of material behaviour, it will be possible to form proper conclusions. They will allow data in material bases to be extended and they will help apply state-of-the-art additive manufacturing technology for the production of components for modern machinery and equipment.

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Koncepcja przeprowadzenia próby skręcania elementów ze stali 20CrNiMo2-2 wytworzonych z zastosowaniem technik przyrostowych

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Streszczenie. W ostatnich latach przyrostowe techniki wytwarzania, a w szczególności druk 3D, są jednymi z najszybciej rozwijających się metod produkcji różnych elementów. Pozwalają one na wykorzystanie jako materiału budulcowego nie tylko polimerów, ale również kompozytów czy metali. Produkty powstałe z zastosowaniem opisywanych technik znajdują zastosowanie w różnych dziedzinach życia, dla przykładu w medycynie, architekturze, rozrywce a w szczególności w budowie części i elementów maszyn i urządzeń. Aby lepiej poznać i określić właściwości wytrzymałościowe wyrobów, kluczowe w przypadku wykorzystania produktów druku 3D w dziedzinie mechanicznej, poddaje się je wielu badaniom np. statycznej próbie rozciągania. Rozważanym pomysłem jest przeprowadzenie statycznej próby skręcania walcowych próbek wytworzonych z wysoko-gatunkowej stali 20CrNiMo2-2 z zastosowaniem techniki selektywnego spiekania proszku metalu (SLM). Pozwoli ono na obserwację zachowania się materiału oraz wyznaczenie konkretnych wartości właściwości wytrzymałościowych, takich jak maksymalne naprężenia styczne występujące w materiale oraz moduł sprężystości poprzecznej (modułu Kirchoffa). Dzięki ich znajomości możliwym będzie porównanie ich z wynikami badań przeprowadzanych nad elementami wytwarzanymi w inny sposób (np. próbka z litego pręta ciągnionego).
Słowa kluczowe: przyrostowe techniki wytwarzania, druk 3D, statyczna próba rozciągania, statyczna próba skręcania