

Mechanical properties determination of AM components

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Abstract. Characterisation of engineering materials and components is a crucial part for design and save service life utilization. Due to components processing technologies and exploitation conditions local properties can significantly vary from location to location over larger components as well as over small material volumes with gradual material changes such as welds, coatings or additively manufactured parts. The current paper is dealing with local properties characterisation for additively manufacture (AM) components by micro tensile test (M-TT). Components produced by additive manufacturing techniques yield properties variation in dependence of the considered location within the component regarding to direction in relation to deposition process. Properties vary over the thickness, length, angle or contacts with the supporting structures necessary for a successful components production by additive manufacturing techniques. The properties differences are mainly related to varying heating/reheating and cooling conditions at various locations of usually very complex parts produced mainly by these technologies. The standard testing procedures fail to characterize such local properties of complex shaped objects due to large size requirements on specimens. Therefore, new techniques have to be established for such detailed local characterizations. Results of miniaturized tensile tests application for local properties and orientations are shown here.

1 Introduction

Additive manufacturing (AM) undergoes dramatic development within last few years thanks to big development leap in metal printing technology development and dissemination of a large number of machines for AM among customers. This leads to large application of AM and increased demands on AM produce parts characterization.

Materials produced by AM exhibits some peculiarities in comparison to standardly used semi-products. Standard material products available on market are usually provided, in forged state when almost homogeneous material properties are attained with rather small anisotropy. However, AM products exhibit strong properties dependence on the process parameters, e.g. position within depositing chamber, building orientation (longitudinal, vertical), building direction (initial wall, final outer wall..), specimen/component volume and so on. Therefore it is crucial to be able to measure local properties, which is for most cases impossible with the use of standard sized specimens, due to the experimental material volume requirements. In many cases it is not possible to determine properties with standard sized specimens as the component is smaller than standard specimens. When standard specimen is produced separately, it has different properties, due to different build procedure, heat transfer that results in slightly different properties from a real component. Therefore, specimens with appropriate dimensions fitting into the components produced by AM shall be used. Mini-specimen methods were developed especially for residual



service life assessment, such as Automated Ball Indentation (ABI), Small Punch Test (SPT) [1-2] or recently methods using miniaturized standard sized specimens [3-11]. ABI can provide quite variable performance for various materials and thus it not generally widely used and in the case of complex thin walled structures produced by AM it would be also in many cases hardly applicable. Much often is used nowadays SPT. Its drawback is that there is need for known correlation between the SPT specimens and standard sized specimens, which is quite demanding on materials and testing in order to have reliable correlation for each specific material considered. The problem with AM parts is that its properties partly depend on the specific part dimensions and thus it is rather impossible to obtain correlation between standard sized specimens and SPT for AM components. Moreover, in the case of AM parts the anisotropy is also important issue but as SPT is using disc specimens biaxial loaded, SPT provides information on behaviour in one plane, but not direction as standard test such as tensile test, notch toughness test, fatigue test.... All these facts lead to necessity of miniaturized standard specimens' application for AM parts properties characterisation.

This paper demonstrates small specimen's technique application for local tensile properties assessment. Mini-Tensile Tests (M-TT) developed and verified in in [3-11] are applied here for part of the total hip replacement set produced by AM. The material investigated is Ti6Al4V (also known as Ti grade5). Local properties in different orientations are investigated for several sampling locations across the component of interest.

2 Experimental material

The component investigated here is made of Ti6Al4V produced by Selective Laser Melting (SLM) powder bed based AM technology. The standard set of printing parameters was used for the part building. Commercially available Ti-powder was used. Detail of powder particles can be seen in figure 1. There is clearly seen nice globular shape of the particles. The size of the particles is ranging from 10 to 75 μm .

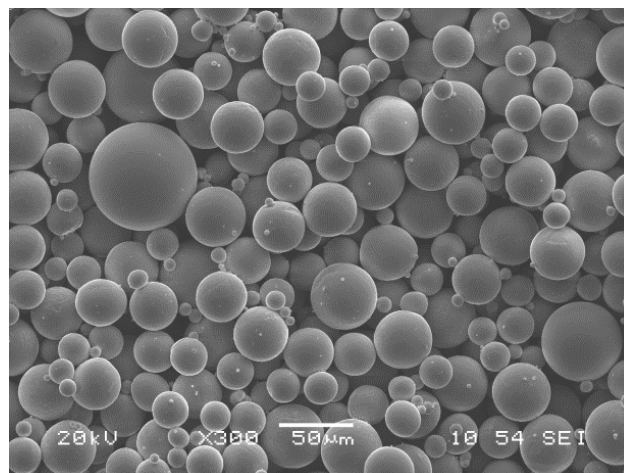


Figure 1. Micrograph of the powder particles.

In order to assess local properties variation across the component investigated, several sampling locations and two sampling orientations were chosen. Four sampling locations evenly distributed over the component length were chosen. At each of the locations longitudinal and transversal directions were investigated. Sampling scheme can be seen in figure 2 together with sampling locations designation.

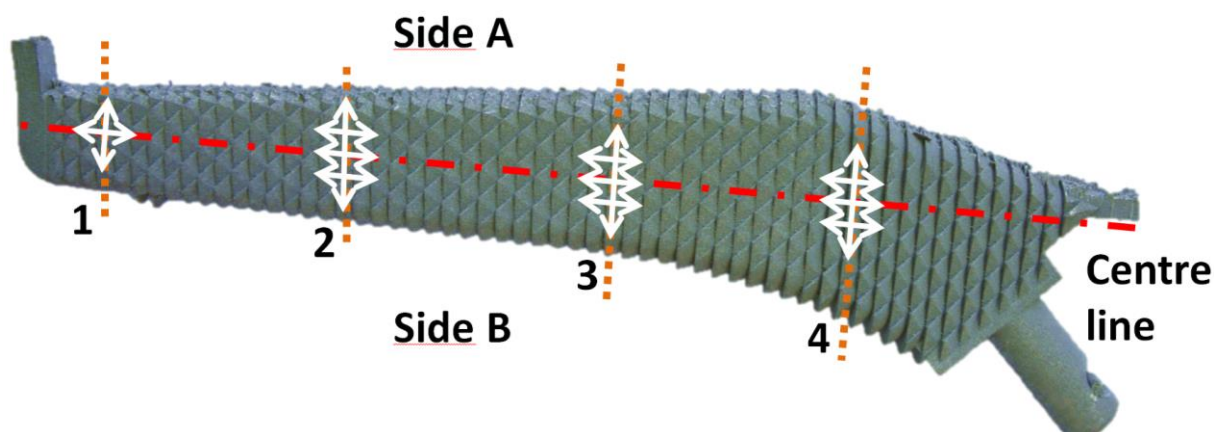


Figure 2. Sampling locations and designation.

3 Tensile tests

Mechanical properties characterization of the material investigated was carried out with the use of Mini-Tensile Tests (M-TT). M-TT testing procedure was verified and performance was shown for example in [7-11]. In the current study, proportional specimens with the geometry according to figure 3 were applied.

Specimens were machined from locations depicted in figure 2. Blocks of the experimental material for M-TT specimens were cut from the component with the use of metallographic saw at first. Subsequently, specimens machining was done by milling following procedures assuring the samples machining influence minimization. Samples plane orientation was perpendicular to the centre line.

Testing was performed under quasi-static loading conditions at room temperature with the use of linear drive based testing system with load capacity of 5kN. Strain was measured with the use of digital image correlation system ARAMIS by GOM. Three specimens per location were tested in the longitudinal direction, except the location 1, where small material volume prevented to have more samples in different orientations. In the case of the transversal direction single specimen per location was investigated. Prior to and after testing specimens dimension were measured for standard parameters determination. Offset yield stress YS, ultimate tensile strength UTS, uniform elongation at maximum force UE, elongation EL and cross section reduction CSR were evaluated. Examples of the obtained tensile records can be found in figure 4. Summarized averaged resulting values of tensile test can be seen in table 1.

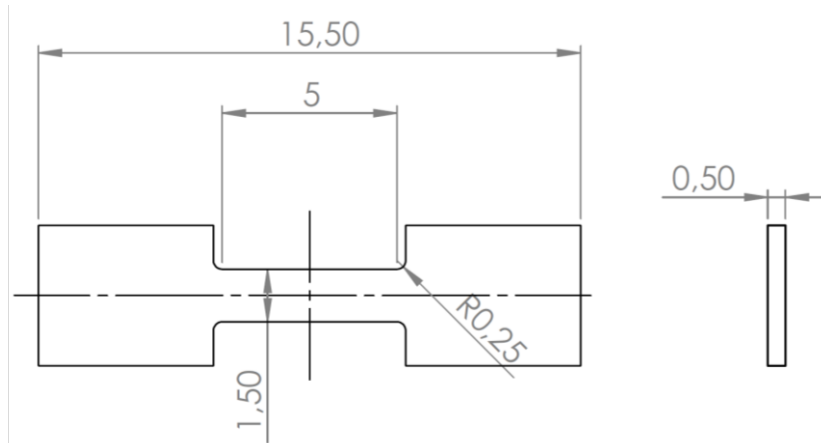


Figure 3. M-TT sample geometry.

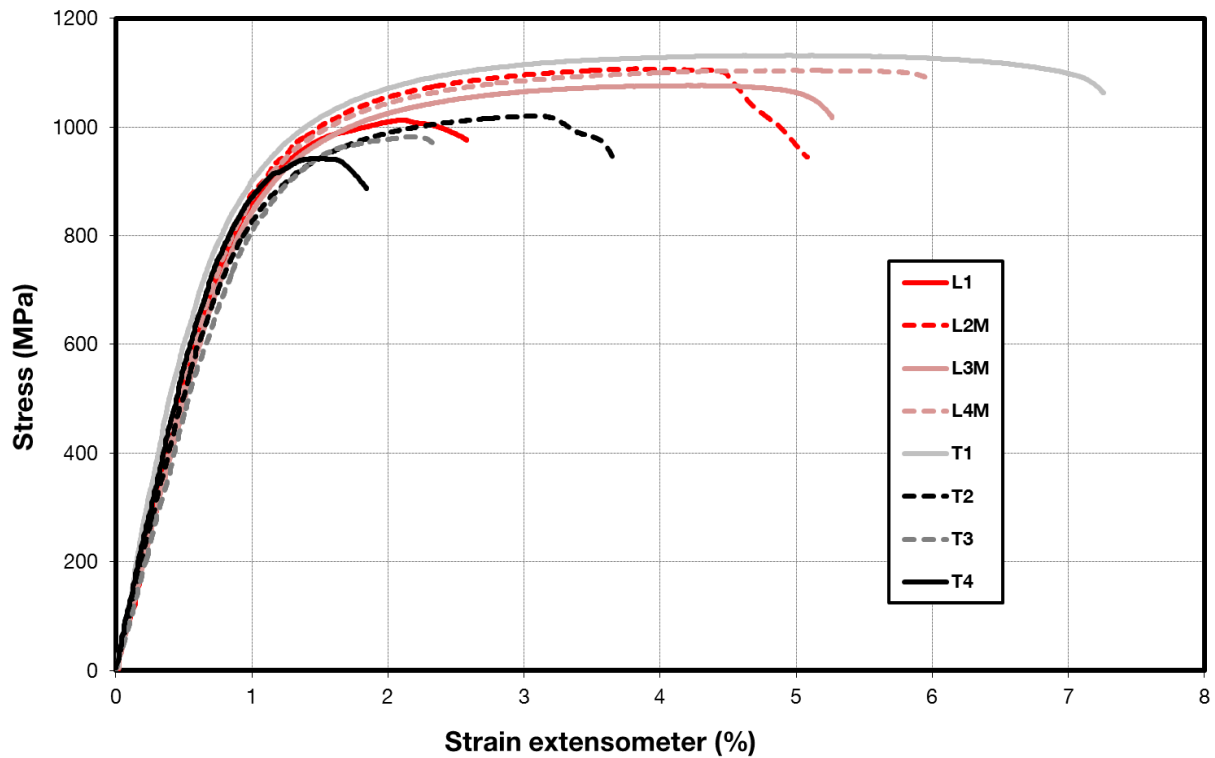


Figure 4. Tensile test records for considered locations and sampling directions.

Table 1. Tensile test results.

Specimen	YS MPa	UTS MPa	UE %	EL %	CSR %
T1	844,3	1131,7	4,1	7,2	28,0
T2	827,4	1020,6	2,1	3,7	13,8
T3	841,0	982,3	1,2	2,4	14,6
T4	848,8	942,5	0,6	1,9	16,4
L1M	880,2	1012,9	1,1	2,6	12,4
L2A	1044,4	1101,7	0,8	2,8	20,3
L2M	904,2	1106,7	2,7	5,1	13,5
L2B	904,0	1130,7	3,6	6,1	12,3
L2 average	950,8	1113,0	2,4	4,7	15,4
L3A	902,0	1099,3	3,0	4,6	23,1
L3M	881,1	1076,5	3,2	5,3	13,1
L3B	892,7	1090,6	4,3	6,2	15,2
L3 average	891,9	1088,8	3,5	5,4	17,1
L4A	908,2	1121,1	4,7	7,6	21,7
L4M	891,0	1104,6	4,1	5,9	27,1
L4B	890,5	1092,8	3,7	6,2	19,7
L4 average	896,6	1106,1	4,1	6,6	22,8

4 Results discussion

The results summarized in table 1 show variation of over 20% in yield stress and tensile strength values and even higher in elongation values across the component investigated.

The transversal tensile properties exhibit clearly monotonic decreasing trend of the ultimate strength values from the location 1 towards the location 4 with the same decreasing trend of the plastic behaviour described by the uniform elongation and elongation. Noticeable embrittlement can be seen here where the original UE 4,1% at the location 1 is decreasing up to the final 0,6% at the location 4. However, the yield stress is almost constant for all considered sampling locations.

Observation of the longitudinal results point out rather uniform values of the yield stress across the component, except outlying value for the specimen L2A, that has to undergo some further analysis. The longitudinal tensile strengths show lower value at the location 1 with similar values at the other sampling locations. There can be seen slight ductility increase towards the location 4 when elongation values are observed. Cross section reduction values exhibit higher scatter, but the averaged values follow the same trends as elongation and thus were not discussed separately.

Taking into account longitudinal and transversal test results there seems to be opposite trend in the properties evolution. While the lowest transversal tensile strength with the lowest elongation is found for the location 4, the same location exhibits the best longitudinal values.

5 Conclusions

The paper was dealing with the local properties characterization of AM component made of Ti gr. 5 alloy. Tensile properties were investigated at different component sampling locations in two directions at room temperatures under quasi-static loading conditions. Miniature tensile (M-TT) specimens were employed here for the properties assessment.

The records obtained with the use of M-TT exhibited very good repeatability. Almost identical records in the initial part were obtained; proving well established test methodology from samples preparation up to tests itself execution confirming M-TT methodology application to AM parts characterization.

Concerning the properties assessment across the component of the interest, there can be found certain properties anisotropy when longitudinal and transversal properties are considered. The longitudinal direction is following the build-up layers during printing, while the transversal direction goes across the build-up layers. The longitudinal properties are very similar according to all considered parameters, however the transversal properties exhibit gradual decrease from the thinnest part towards the thickest one. This change of about 200MPa is noticeable and some explanation for this change should be provided by further metallographic investigations.

The study shown here provided detailed investigation of local properties measurement of AM component with the use of M-TT technique. Applicability of this method for AM parts was demonstrated here providing deeper insight into local material behaviour enabling information for AM technology improvement toward tailor made properties in different directions. Additionally, local data that can be used as input data for FEM simulation and subsequent optimization of AM component can be considered as another important output of these measurements. Local properties information together with design and AM processes parameters optimization will lead to better components functionality and lower undesired components failure rate.

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