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Mechanical and dimensional characterization of multi-material additive manufactured parts

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Abstract: Multi-material additive manufacturing brings new possibilities for the production of flexible and functional medical models for training and planning of surgical interventions. Based on the large amount of available material combinations, materials are poorly characterized and process related variations in the material properties are not completely understood. Aim of this study was a dimensional and mechanical characterization of selected pure materials and material-combinations under investigation of build orientation effects.

I. Introduction

Additive manufacturing systems, based on the material jetting technology are uniquely qualified for the production of complex medical models that can be used for surgical training, pre-operative planning and research purposes. This technology enables the production of colored and flexible structures with different mechanical properties by combination of various materials. Medical models, printed from flexible materials are especially suitable for planning implantation procedures of medical devices and allow practicing of surgical stitches and cuts. [1] For the design and manufacturing of medical models, it is essential to understand the process related variations in dimensional accuracy and mechanical properties. Studies on multi-material part characterization are rare and show limitations based on non-standard compliant investigations. To investigate process related variations, various experiments for mechanical and dimensional characterization of multi-material parts, manufactured on an Objet500–Connex3 3D-printer (Stratasys Ltd., Eden Prairie, Minnesota, USA), were performed in accordance with ISO standards. In this paper, results of tensile tests and dimensional accuracy measurements are presented.

II. Material and methods

For mechanical characterization, tensile tests were selected amongst listed testing methods in ISO 17296-3. Four soft and four rigid materials were tested in three build orientations (XY, YX, ZX), using Type 1A specimens specified in ISO 527-2 (see Figure 1). The studied materials are the soft material Tango+, the rigid photopolymer VeroClear and the mixtures FLX9950, FLX9970, FLX9995, and RGD8625. In addition, two further rigid pure materials were evaluated (VeroPureWhite and the biocompatible material MED610). All tested materials are produced by Stratasys Ltd. (Eden Prairie, Minnesota, USA).

The tensile specimens were further checked for their dimensional accuracy by means of measuring equipment specified in the standards. For statistical evaluation of differences between the orientation levels a one-way ANOVA was performed. To provide information about which groups have significantly different means, multiple comparison tests with Bonferroni correction were conducted.

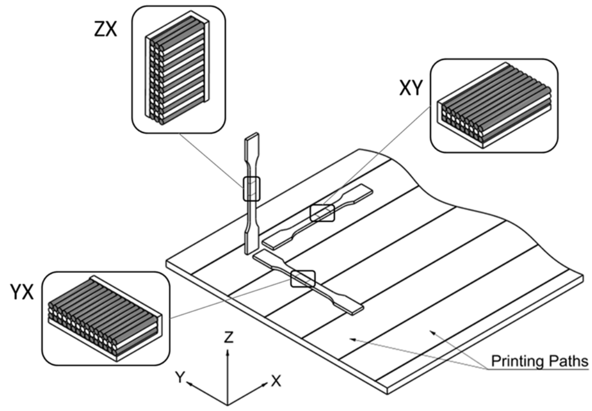

Figure 1: Studied build orientations of the Type 1A tensile test specimens for investigating the mechanical properties and dimensional accuracy.

III. Results and discussion

Results of the tensile tests demonstrate that there are statistically significant differences in the tensile properties between different build orientations (see Figure 2 and Figure 3). In general, XY-orientations show the highest tensile strength and tensile modulus, followed by YX- and ZX-orientations.

Determined tensile moduli are in the range of 0.2 to 2500 MPa, comparing well with moduli found in biological soft tissues (see Table 1). For mimicking hard tissues such as cortical bone, the investigated materials do not provide sufficient mechanical stiffness. Whereby the determined highest tensile moduli are still one order of magnitude below the tensile modulus of cortical bone. Shrinking of the printed specimens was found to be more prominent in vertical oriented specimens and especially for soft materials.

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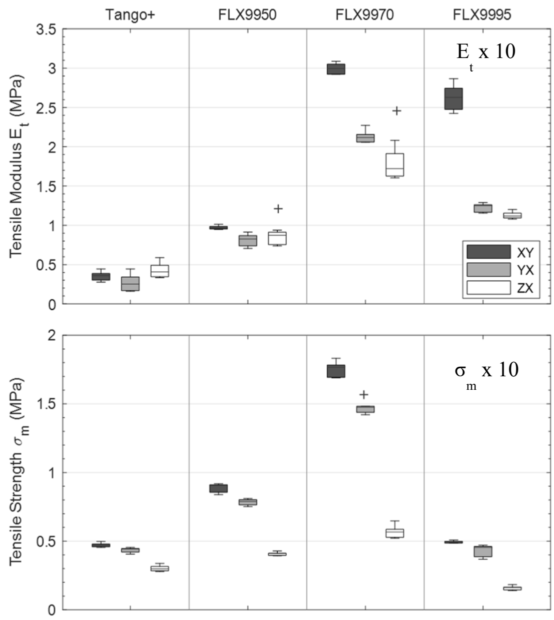

Figure 2: Soft materials - Boxplots of the mechanical data determined on the four soft materials at three different orientation levels. (n = 6 for each of the three orientation levels)

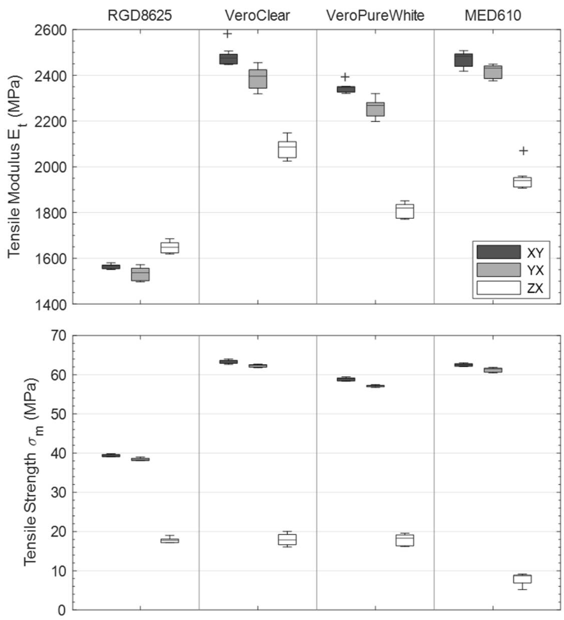

Figure 3: Rigid materials - Boxplots of the mechanical data determined on the four rigid materials at three different orientation levels. (n = 6 for each of the three orientation levels)

Table 1: Tensile modulus of soft tissues found in literature, reproduced from [2]

	Tensile Modulus E_t	
Tissue	**Range (MPa)**	**Average (MPa)**
Tendon	43-1660	~ 560
Muscle	480	480
Skin	21-39	~ 30
Liver & kidney	1-15	~ 10
Cornea	0.1-11.1	~ 3.0
Sclera	0.6-4.9	~ 2.7
Spinal cord & grey matter	0.4-3.6	~ 2
Artery & vein	0.6-3.5	~ 2

For these specimens it was found that material-combinations, containing higher percentage of Tango+ are characterized with a higher shrinkage, which was up to 4.6 % for the pure material (Tango+).

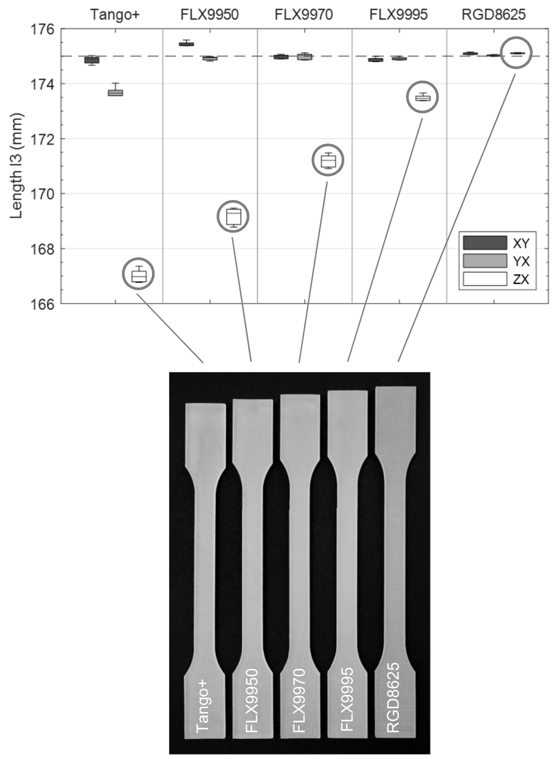

Figure 4: Boxplots of the measured specimen length (n = 6). The dashed line indicates the nominal length of the specimens (175mm). Encircled boxplots show the determined length of vertical (ZX) printed specimens for different material-combinations.

IV. Conclusions

In conclusion, a wide range of tests were performed investigating the mechanical and dimensional properties of material jetted specimens. For the design of medical models orientation effects on the mechanical properties and the dimensional accuracy need to be taken into account. Further material evaluations, such as viscoelasticity measurements are currently being performed.

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AUTHOR'S STATEMENT

Conflict of interest: Authors state no conflict of interest. Ethical approval: The research related did not involve neither human studies nor animal experimentation. Therefore, no institutional review board application was necessary. Informed consent: informed consent has been obtained from all individuals included in this study.

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