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Fatigue crack propagation in a component produced by additive manufacturing of polymer materials

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1. Introduction

Additive manufacturing is a layer-based manufacturing process which allows automatic fabrication of products of complex shape at optimized cost with reduced time. In the last decade, the application of additive manufacturing has grown significantly, mainly due to the availability of comparatively inexpensive 3D-printing devices [3]. As the relatively inexpensive process is definitely the advantage, on the other hand, it has been widely believed that components produced by this method have slightly worse mechanical properties in comparison with conventionally produced homogenous components, due to existence of weld lines [4]. However, recent studies proved, that the negative effect of weld lines can be reduced by choosing appropriate welding conditions during the printing process [2].

Fracture properties and crack growth kinetics of PLA (polylactic acid) were studied by Arbeiter [1] in a series of measurement on CT specimens with different line orientations. The results showed that regardless of the orientation of the lines, the cycles to fracture and to initiation as well as the crack initiation and propagation law appear to be almost identical. Based on these results, a Paris' crack propagation law was used for the crack propagation description, and the material constants were determined: $A = 10^{-3.78}$ and $m = 2.87$ [1]. In order to verify the validity of the obtained material constants, a study of crack growth in a real mechanical component – a wrench – made of PLA material has been in progress. The main aim of presented study is to create a 3D numerical model containing a crack that will allow calculation of the stress intensity factor along the crack front and estimate a residual fatigue lifetime of the modeled wrench with consideration of a growing crack from given initial size to the final one. Finally, the comparison between estimated fatigue lifetime value and experimentally obtained one was done.

Fatigue tests were carried out on the plastic wrench mounted to a steel nut, which was fixed. The wrench was cyclically loaded by force in a range of 24 N to 40 N with a loading ratio R of 0.1 at room temperature. A scheme of the experiment with basic dimensions of both components is shown in Fig. 1. Tests were aborted when maximum displacement of the machine was reached. Fatigue experiments were carried out at Polymer Competence Center Leoben, Austria.

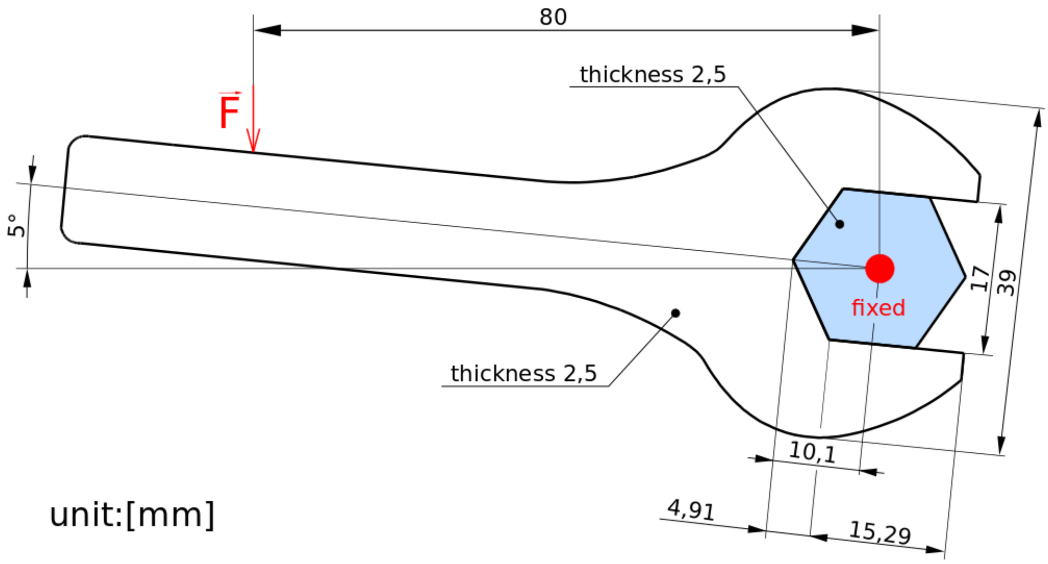

Fig. 1. A scheme of the experiment with basic dimensions of both components

2. Numerical modeling

The numerical modeling was chosen due to the complicated stress field near the crack front, that is influenced by contact stresses and by the stress concentration caused by sharp edge, where the crack initiated. During the crack propagation modeling, the assumption that the crack propagates as semielliptical was taken into account. A typical 3D numerical model contained between 5×10^6 and 9×10^6 isoparametric elements depending on the crack size. The finite element mesh was prepared very fine near the crack front to describe the singular stress field near the crack front properly (see detail in Fig. 2). Keeping both parts in contact during the simulation was secured by COMBIN element (highlighted by purple color) and by using contact elements between both models (highlighted by green color), see Fig. 2.

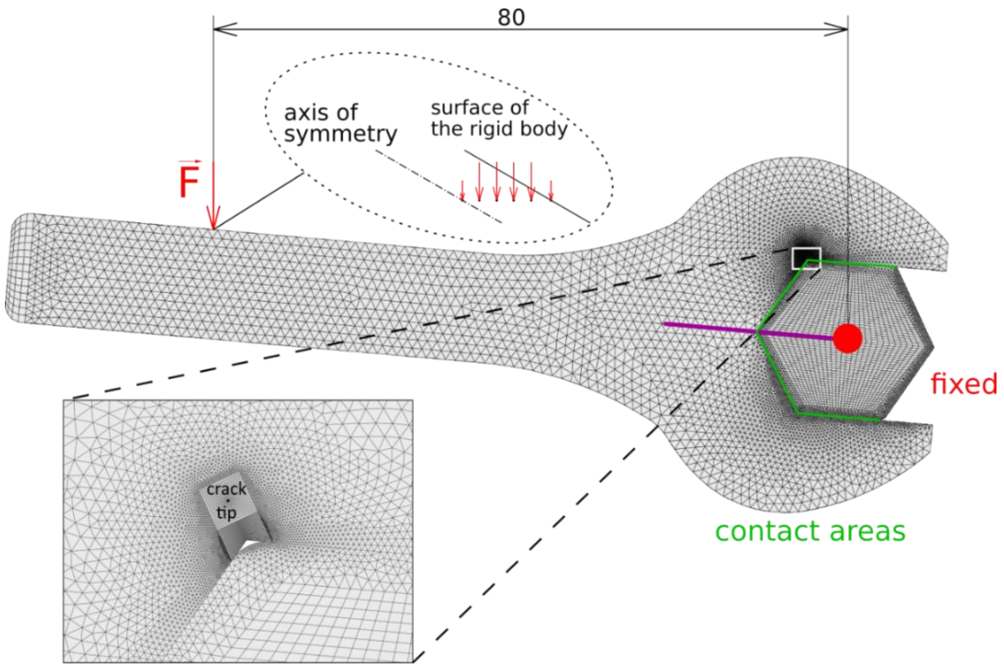

Fig. 2. 3D Finite element model containing a crack. Very fine mesh around the crack tip is shown in the detail

The loading force was distributed symmetrically on the width of the wrench, see detail in Fig. 2. The elastic properties of both materials taken in the optimization are shown in Table 1.

Table 1. Basic elastic properties of both materials

Material properties:	Young's modulus [GPa]	Poisson's ratio [-]
Plastic wrench	3.4	0.37
Metal bolt	210	0.33

The crack propagation was modelled by crack increments, i.e. number of steps (numerical calculations with extended crack by chosen crack increment) were performed during numerical simulation of crack growth from initial to the final size. The size of initial defects from the printing pattern was between 50 and 100 μm according to the fracture surface. Therefore, the crack length for the first numerical step was chosen 50 μm and the initial crack was of semicircle shape. As the crack was growing the crack front shape was continuously changing to a semielliptical one. The semielliptical crack was modeled up to crack length when the crack front reached surface of the wrench. Therefore, approximately to 2 mm due to very fine mesh in the crack surrounding. For higher values of the crack lengths, the straight crack front shape was considered.

3. Conclusion

This numerical model allows calculation of the stress intensity factor along the crack front, where the crack growth is simulated in steps and two models of cracks are considered. The first one covers the short crack lengths up to 2 mm, where the semielliptical crack front shape is assumed. The second model can be used for crack lengths values from 2 mm and the crack front shape is considered as straight – as the crack grew through all the thickness of the model. The obtained stress intensity factor values were used for numerical estimation of residual fatigue lifetime of the wrench. The comparison with experimental date was done and good agreement has been found. The work presented contributes to the better understanding of fatigue crack behavior in 3D-printed PLA materials.

Acknowledgements

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