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Introductory Analysis for Fatigue Testing of MEX Parts

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Abstract
The paper discusses the use of 3D printing technology in the production of machine parts and the impact of production parameters on load-bearing capacity. Numerical simulations and stochastic theories are used to determine the effects of cyclic external loading conditions, which are typical in the vehicle industry. However, these numerical simulations must have many material property parameters. The study focuses on the material characteristics of Material Extruded (MEX) polymers, specifically PLA, and the impact of production direction and manufacturing parameters on the material's properties. The paper concludes that further investigation is necessary to determine specimens' dynamic load-bearing capacity and understand orthotropic materials' behavior.
Keywords
additive manufacturing, orthotropy, orientation, material properties, MEX

1 Introduction

3D technology nowadays is an everyday technology. Today's applications are not only for marketing and rapid prototyping. These products are built into machines [1]. The cost and time of the production equipment can be saved by this technology [2]. To apply as a load-bearing element, the load capability of the material must be known [3–5]. Several numerical simulations must be carried out [6–8]. Dynamic stresses also develop in the case of cyclic external loading conditions [9]. These are typical vehicle industry applications [10–12]. For these cases, the machine parts must be designed for dynamic conditions where the material characteristics – dynamic and fatigue – must be known [13, 14].

From everyday experience, it is well known that the external loading conditions act on the machine parts and the complete machine as a function of time to a small or greater extent. A static or constant load in time can be interpreted as an idealized limit state. In the case of vehicles, the service conditions (i.e., in the case of off-road conditions) change unsystematically in terms of value and frequency. Based on these facts, the loading conditions can be determined by unsystematic functions. Stochastic theories can describe or predict the process using statistical parameters [15, 16]. The failure process in part (material) due to the variable loading conditions essentially differs from the failure process in the static case. On the surfaces of machine elements (test specimens), especially in the neighborhood of the notches, peak stress areas make the change, in general, the external load starting from the crystalloid grid failures may cause micro-cracks. Macro cracks could develop from micro-cracks growth during the fatigue process [17].

During the crack propagation process, the cross-section decreases; in this way, the failure can develop in the case of a finite cycle number [18]. Starting from this fact, the time-dependent parameters must be determined to describe the fatigue process [19]. In case of the determination of limit fracture conditions ($\sigma_M = C$. mean stress, $\sigma_A = C$ amplitude, sinusoidal process), as a result, a 3D function is realized $\{\sigma_M; \sigma_A; N_t\}$. The best-known representation of the generated boundary surface is shown in Fig. 1 [20].

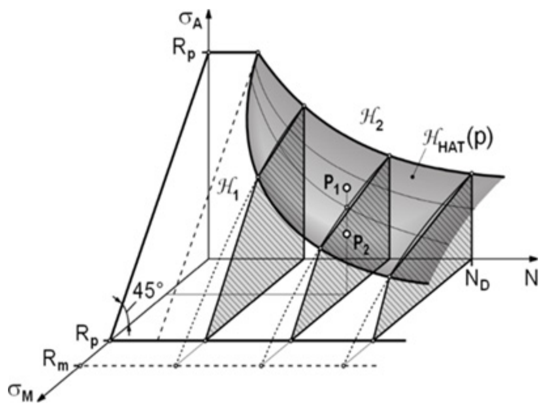

Fig. 1 Limit surface in case of $\sigma_M = C.$, $\sigma_A = C$ [20]

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The plane section of the limit condition's area is used for investigation. In the case of $\sigma_M = C$., the $\{\sigma_A; N\}$ Wöhler curve, and $N = C$. The $\{\sigma_M; \sigma_A\}$ Haigh diagram is used for investigation [20].

2 Methodology

The fatigue investigation was realized below the yield limit, as indicated in Fig. 1. To realize this, the static material parameters must be determined in our case for the PLA material. The alternating load has zero mean value during the fatigue test, and the push and pull test diagrams must be determined. The material produced by additive manufacturing technology shows anisotropic material properties because of the layer-by-layer technology [21]. That means the material shows different behaviors in the push and pull directions. It causes other difficulties: the material parameters differ according to the production direction [22–26].

In addition, manufacturing parameters significantly impact production costs [27]. In addition, the manufacturing parameters significantly affect residual stresses and residual deformation [28]. The push-pull tests (stress-strain curves) will be carried out on a standard test machine (INSTRON 8872, Budapest, Hungary) with short cylindrical specimens to avoid buckling. (DIN 50125:2009-07 [29], Type A). The printing layout and this type of specimen can be seen in Fig. 2.

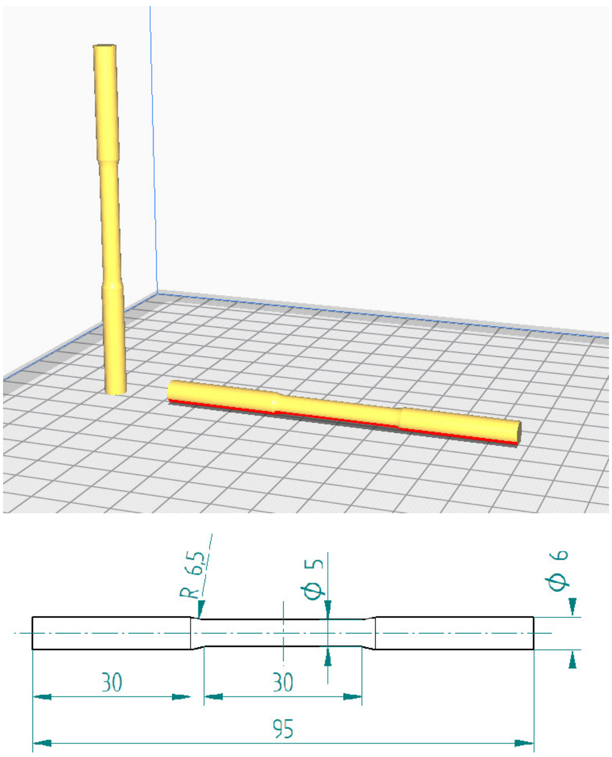

Fig. 2 Printing layout (laying and standing position) and the geometry of the test specimen

3 Experimental results

Tensile and compression tests were made on the specimens. The tensile and compression speed was the same, five mm/s by the standards. Test specimens have been produced in two different production directions (laying and standing position) (Fig. 2), as the results are indicated in Figs. 3 and 4.

4 Discussion

As a result of the investigation, as shown in Fig. 4, the load-bearing capacity of the specimen printed in the

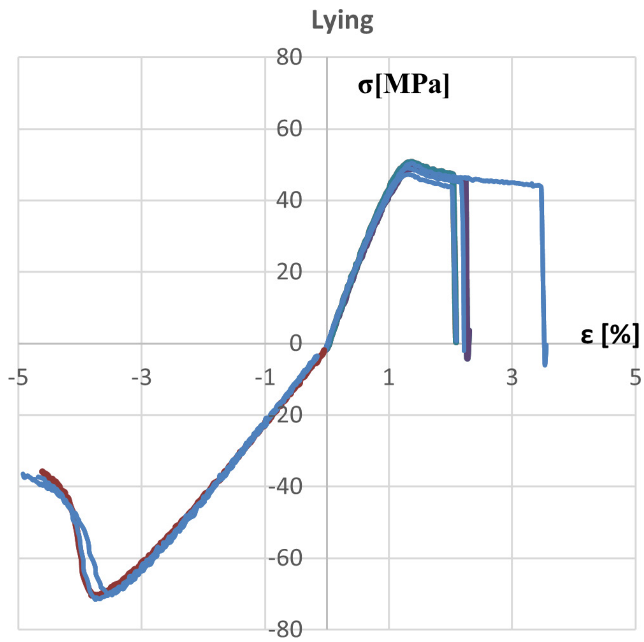

Fig. 3 Stress-strain diagram in laying position

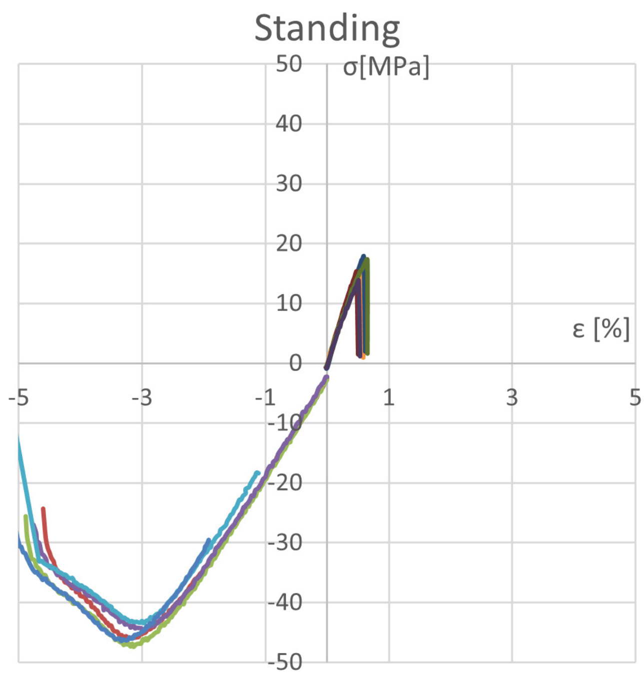

Fig. 4 Stress-strain diagram in standing position

laying position in the push loading direction is about 50% larger than in the pull loading direction.

The difference between the results in load bearing capacity of the push and pull tests in the standing (vertical) printing direction is much more significant (nearly three times). The differences between the load capacities of the lying and standing specimens in tension and compression are shown in the middle part of Fig. 4.

A significant result is that the measure of the orthotropy is different between the compressive and tensile load directions. It can be clearly observed that the difference in the case of load-bearing capacity in the pull direction is about threefold, but in the push, the direction is only about 1.5-fold.

Nevertheless, considering the differences between strengths, it is surprising that there are no significant differences between the Young moduli, as observed in the lower part of Fig. 5. The differences between Young moduli of the specimens printed lying and standing position are nearly the same, about 1.28 times in tensile and compression load.

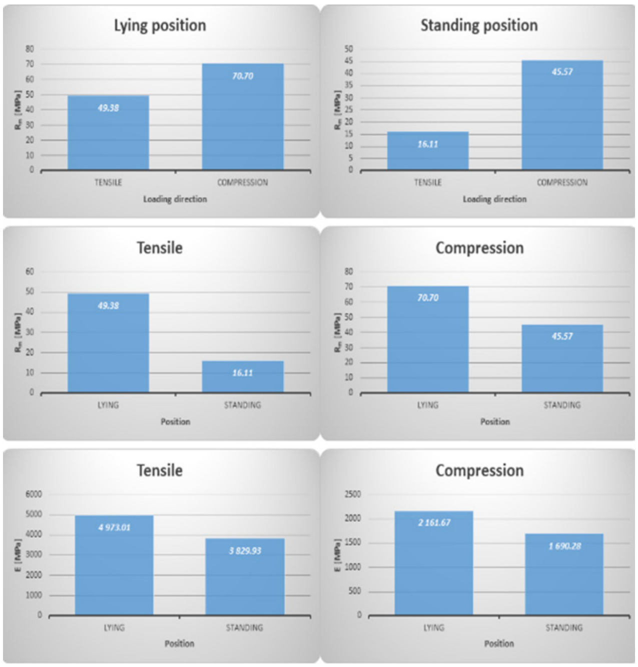

Fig. 5 The ultimate strengths and the Young moduli of the printed specimens in case of tensile and compression load

5 Conclusion

To determine the dynamic load-bearing capacity of specimens is necessary to examine the effects of the cyclic loads in the push-pull state. In the case of the Whöler investigation, the tests must be carried out in 90% of the material's yield point. This value in the case of polymers differs in the push and pull directions. The description of the problem of a material that behaves in an orthotropic way is much more complicated. Another question is the time-dependent behavior of the polymers (creep, relaxation). The last difficulty of investigating polymers is the dependence of behavior on the test speed of the applied load.

Based on the above, it can be concluded that the results available in the literature so far are not sufficient to establish fatigue properties.

Furthermore, it is important to note that the fatigue design of parts produced by FDM additive manufacturing is a very complex task. The expected fatigue limit can only be estimated with a very high uncertainty for stochastic workflows and complex loading cases.

The potential for design errors is increased because the real stresses are often difficult to predict.

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