

External examiner's review of a Master's thesis

Student's name and surname: Aleksí Modebadze
Degree programme: Polymer Engineering
Department: Department of Polymer Engineering
Supervisor of the Master's thesis: prof. Ing. Tomáš Sedláček, Ph.D.
External examiner of the Master's thesis: Ing. Jan Musil, Ph.D.
Academic year: 2024/2025

Title of the Master's thesis:

Analyzing of Feeding Behaviour of MEX Extruder Heads

Assessment of the Master's thesis using the ECTS grading scale:

Assessment criteria	Assessment according to the ECTS
1. Fulfilment of the assignment criteria	C – Good
2. Level of quality of the formal aspects of the thesis, including the level of linguistic quality	C – Good
3. Amount, topicality and relevance of the literature sources consulted	C – Good
4. Description of experiments and implementation methods	C – Good
5. Level of quality of processing of the results	C – Good
6. Interpretation of the results achieved and discussion thereof	C – Good
7. Formulation of the conclusion of the thesis	C – Good

Select the option the submitted thesis for defence and propose the following assessment:

C – Good

Comments on the Master's thesis:

Diploma thesis of student Aleksi Modebadze is focused on theoretical and experimental study of filament feeding behaviour in 3D print technology. As a hardware developer in 3D printers production company Průša Research I'm very interesting in this topic because the maximum feeding force is one of the most limiting technological factors of current 3D printers. However, due to quick and non-isothermal melting of filament in the heat block following extrusion behaviour is very complex and still not fully understood yet. Due to this fact, each scientific work focused on this topic is highly desirable.

Firstly, I shortly summarize the reviewed Master thesis together with my comments, remarks and recommendations. In the Introduction part, there is written that "(extrusion) force is affected by the temperature, material viscosity, and extrusion velocity...", but dimensions (diameter and length) and especially melting capability of the nozzle (standard or so-called "high flow" type) are important as well. In the following theoretical part, material extrusion (MEX) technology used in additive manufacturing is firstly shortly introduced. Secondly, feeding behaviour and extrusion force in MEX are presented. However, it should be valuable (at least shortly) to describe melting behaviour in the heat block as well. Slow increase of extrusion force followed by its rapid growth with gradual extrusion speed increase is primarily caused by insufficient melting (short melting zone/high extrusion speed) which is surprisingly not mentioned in this section. Thirdly, chosen materials particularly ABS and composite of 316L metal powder with POM as a binder are described. In the section focused on chosen ABS polymer, there are three tables summarizing drying conditions, density and tensile/flexural properties. However, much more important printing conditions (i.e. recommended processing temperature(s), cooling conditions, extrusion speeds etc.) or basic rheological properties (at least MFI) are missing. Then, in Experimental Approach section, methods, devices and conditions used for characterization (DSC, capillary rheometer, and devices for thermal conductivity and pVT determination) and testing (3D printer setup) of chosen materials are presented. Moreover, basic rheological models (power-law, Cross model) together with models for temperature-dependent viscosity (Arrhenius and WLF) are shortly introduced. Here, it should be valuable to mention also temperature ranges in which both temperature-dependent models can be used. Finally, numerical simulations including calculation methods, governing equations and material models used in this work are introduced. Moreover, essential mathematical simulation setup in Ansys Polyflow software, generalized Navier slip law and boundary conditions are also defined in this section. Generally, from clarity point of view, I would recommend to separate theoretical description of methods and models (theoretical part) and particular testing conditions used in this Master thesis (practical part). Also, separate section describing aims of the work which are only shortly described in the beginning of Abstract would be valuable.

In the practical part, results of material characterization, particularly DSC, density (pVT diagrams), thermal conductivity and shear viscosity curves are firstly presented. Here, in the case of shear viscosity of Ultrafuse 316L composite material error bars calculated from several repeated measurements or measurement performed at different university (mentioned in the text) should be add to Figure 28 for better understanding of viscosity range and measurement error of this material. Then, results of experimental extrusion force measurement followed by its numerical simulation at different temperatures with and without wall slip are also presented. Here, the most important graphs are Figures 40 and 41 depicting comparison of measured and calculated extrusion forces for Ultrafuse ABS polymer at different temperatures for wall slip and no wall slip conditions, respectively. Here, firstly, in both graphs, different ranges of y-axis (measured/simulated) extrusion forces are used which is however not ideal for comparison

between reality and prediction (at first sight it seems that simulated forces are higher than ones experimentally measured). Secondly, the shape of the curves are opposite - experimentally measured extrusion forces has convex parabolic shape while calculated extrusion forces has concave parabolic shape. Thus, if extrusion force and extrusion speed are recalculated to apparent shear viscosity and apparent shear rate respectively, then experimentally determined apparent shear viscosity will increase with apparent shear rate (this is caused by insufficient melting capability of the heat block - the higher speeds the colder melt is fed to nozzle) while theoretically calculated apparent shear viscosity will decrease with apparent shear rate (standard shear thinning behaviour). This crucial discrepancy should be probably caused by method of extrusion force calculation which is however not discussed in the thesis.

Last but not least, I would add some comments to my evaluation. From formal point of view I found several gramatical mistakes (e.g. verb forms, singular/plural mismatch or missing verbs) and also formal style mistakes (e.g. description of Figures or Tables - mismatch of dot at the end of the sentence or titles of the chapters - mismatch of capital letters). Further, thesis includes 56 literature sources in total of which 34 only are scientific papers or books, others are technical data sheets or general electronic sources. Moreover, I found also several formal mistakes in some references (see e.g. ref. 30 - missing pages or ref. 53 - missing source).

Questions to be asked by the external examiner of the Master's thesis:

- 1) In the Chapter 2 there is written that "...temperature dependent viscosity has great influence on the bonding between layers and affects the mechanical performance and surface finish". Could you please specify what is the ideal temperature dependent viscosity behaviour optimizing above mentioned parameters?
- 2) In Figure 35 and 38 there are calculated velocities in the nozzle centre approximately hundred times lower than the feeding filament speed. What is the reason?
- 3) Could you please specify method how the extrusion force was calculated in the numerical simulation?

In Zlín on 23. 05. 2025

Signature of the external examiner of the Master's thesis