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ScienceDirect

Procedia Manufacturing 21 (2018) 205–212

Procedia MANUFACTURING

www.elsevier.com/locate/procedia

15th Global Conference on Sustainable Manufacturing

Fast and iterative prototyping for injection molding – a case study of rapidly prototyping

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Abstract

Injection molding is essential for mass manufacturing plastic parts in all sizes and shapes. However, predicting the quality of a mold is tricky, and while computer simulations are highly advanced, they rely on conservative models, leading to over-dimensioned parts. Furthermore, it becomes practically impossible to prototype a part with the real materials, since a simple mold drives costs and remodeling thereof is time consuming, if not impossible. By building our own desktop sized injection molding machine, we were able to explore the possibilities of prototyping injection molded parts and test a variety of mold materials in order to quantify the outcomes in a three-point bending test. Subsequently, the learnings were applied to a full-scale model, which was tested in an industrial setting. The outcome shows that one can apply rapid prototyping, and subsequent test-build-iteration circles to mass-manufactured parts, allowing for rapidly optimizing material usage, and user interactions.

Keywords: Prototyping; Wayfaring; Product Design; Additive Manufacturing; Injection Molding;

1. Introduction

In a globalized furniture market, it is important to keep up with current trends in order to stay ahead of competitors. Furthermore, better and cheaper solutions are high in demand, which means that production is either based on cheap manual labor, or fully automated factories. One company that successfully manages to operate out of the high-priced country of Norway is Scandinavian Business Seating (SBS). They manufacture and sell 244’000 chairs worldwide from their production facilities in Røros, Norway. Obviously, such large production numbers require mass-manufacturing methods, such as injection molding. While this is an established means of mass-

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2351-9789
10.1016/j.promfg.2018.02.112

producing plastic parts, consuming about 32wt% of all plastics [1], it also poses several challenges and risks in respect to rapid prototyping and the vision of switching to recycled plastics.

Our work is focused on the fuzzy front end of product development. During this phase, there is a sheer infinite solution space that needs to be explored in order to find the best solution. By iteratively using prototypes to learn [2] and uncover unknown unknowns [3], this process is guided by dynamically emerging requirements. In this article, we argue for rapidly prototyping injection molded plastic components. To support these claims, the test results from a premaster- and subsequent master-project in the prototyping environment TrollLABS are presented: By building a desktop injection molding machine in-house, it was possible to test a large variety of mold materials produced on a variety of 3D printers and a CNC mill. In order to get a comparison to the real part from SBS and simulation results, the most successful attempts were tested in a three-point-bending test. Furthermore, a very complex mold was machined and successfully tested on an industrial injection molding machine.

1.1. Injection molding: Fundamentals

Injection molding works by melting a thermoplastic, and injecting it under high pressure into a cavity where the plastic is left to solidify again. The solid part can then be removed from the mold, while the latter is used over and over again. Designing a good mold is a difficult task, since one has to consider a variety of potential constraints and faults, such as draft angles, warping, and sink marks, to name a few. Machining one steel mold, as they are typically used for injection molding, can easily cost one million Norwegian Crowns (~120'000USD) and in case an error is discovered in the first tests, it has to be shipped back to the manufacturer, which is often in China. Despite all these challenges, injection molding is a fundamental production method for mass-manufactured plastic parts. While one mold is expensive, it can be used tens of thousands of times, subsequently reducing the price per part.

A commonly used plastic for injection molded parts is Polypropylene (PP). While it works great for the manufacturing method itself, it exhibits a problematic range of inconsistencies. It is not homogenous, and the flow during the injection will introduce some anisotropy in the material [4,5]. PP is highlighted since it can be recycled and therefore offers the possibility for a more sustainable product line. It was also the material used for injection molding the small test piece (see section 3).

A common, and great tool for predicting the outcome of an injection molding process is performing a Finite Element Analysis (FEA). The digital model of a part is first split up into volume elements ('mesh'), and one then applies certain mathematical constraints, describing how they interact with respect to e.g. temperature, or stress. The software then calculates all these interactions based on the applied models and allows the designer to analyze the physical conditions, e.g. stress concentrations within the part under certain load conditions, or the flow of a material during the injection process. Simulating the process of injection molding is feasible and also the industry standard. However, while the models improve their accuracy and subsequent fidelity of an FEA simulation, they still do not *exactly* match the experimental data [6]. With respect to recycled PP, the non-linear behavior of the material makes it extremely complex to fully capture the behavior of a part under loading and unloading conditions [7], and including all of these material properties in a model is highly complex, and induces other challenges, e.g. convergence problems [8]. Simulations with simpler, linear elastic models, do make the problem easier to solve, but do not offer the same resolution as a 'perfect' model. Therefore, any design based on simplified models will be over-dimensioned, and subsequently using too much material.

In addition, the more accurate a simulation should be, or the bigger a part, the longer it takes to fully solve the simulation. It is important to point out that a change in the design of a part also requires a highly time consuming recalculation of the previous simulation efforts, thus hindering iterative, physical prototyping.

1.2. Motivation

Given the overview above, this time- and money-consuming approach is not ideal for quick testing of either the mechanical durability of a new part, or the physical feeling thereof. Being able to rapidly prototype an injection molded part therefore helps on multiple levels: Since design-build-test-cycles help to rapidly improve the design during the product development process [9,10], companies should not be waiting for months between two iterations. Furthermore, addressing the different *characteristics* of prototypes, as [11] describes it, means that they have to