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Energy efficiency benchmarking for injection moulding processes

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ABSTRACT

Energy and resource efficiency is becoming an important strategy in manufacturing. In the automotive industry, the assessment of the environmental impact of a product in use-phase is common practice. In contrast, the manufacturing phase often lacks detailed data; potential for improvement gets lost. Analysis and comparative evaluation of how the production factor energy is used in manufacturing can be an impulse for parallel improvements regarding energy, material and process time efficiency. The paper presents a systematic approach to energy efficiency benchmarking in injection moulding, specifically addressing the impact of the mould. A knowledge base serves as a baseline for the process of data collection and evaluation. Additionally, energy efficiency benchmarking of single processes give insight into the effectiveness of improvement measures and allow to identify best practice process and product designs. The concept can be extended to predict energy consumption of production plants. An energy label for moulds is introduced.

1. Introduction

Energy and resource efficiency are promoted as the main drivers to create an environmentally less harmful economy [13]. Besides, the EU proposals for reducing CO_2 emissions in the use phase, the automotive industry, for example, is aiming at ECO-innovations of engine, powertrain and part related technologies. Companies become more and more aware that a market segment, significantly favouring environmentally friendly products, is growing fast. Ideally, an environmentally friendly product should not only consider the use phase but also the manufacturing phase. Currently, a lack of information regarding energy efficiency in manufacturing phase can be asserted in many production processes. Especially in times of withering resources, the consequent analysis of production processes, also in terms of energy efficiency, is a vital basis for improvements.

The reduction of energy and resource consumption during manufacturing is a key opportunity to lower costs. In the past, especially the input factor energy was mostly seen and treated as an invisible resource and overhead costs. The resulting deficit in transparency towards energy consumption in production processes is one major reason for the phenomenon called efficiency gap. The efficiency gap describes the difference between the actual efficiency level in production and the technically postulated efficiency level [19,26,41,43]. Instruments and methods are needed to allow a monitoring and benchmarking of resource consumption for specific products or processes.

Therewith, best practice examples can be identified and measures to foster efficiency can be evaluated economically and ecologically. To promote a sustainable change, such methods or instruments need to be efficient themselves. This means to integrate new instruments and methods into existing processes as supporting elements in such a way, that those will help to optimise processes without increasing overall costs.

In this paper, we are presenting an approach to significantly increase the knowledge of energy consumption with respect to the production of injection moulded plastic parts in the automotive industry. The approach is based on demand-driven monitoring of energy consumption on unit process and therewith technical level. It is reflecting the restrictions of productive environments, especially avoiding interferences and taking into account the process-time relation.

A knowledge base serves as a baseline for a method to assess and estimate energy consumption for specific products. The approach enables manufacturers to benchmark process designs and to identify products with a leading impact on energy consumption. We specifically address the process of injection moulding with a focus on moulds. Especially with regard to injection moulds, the concept of an energy label for moulds is introduced. The approach includes a concept to establish a long-term benchmarking focusing the energy efficiency of injection moulding processes.

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Furthermore, the benchmarking of energy efficiency on unit process level is extended by an approach which can be used to assess the energy efficiency of an entire cost-centre and predict total energy consumption. This facilitates the development of economically and ecologically sustainable production strategies.

2. Theoretical background

2.1. Energy efficient injection moulding

To achieve a more environmentally friendly production, there are basically two options available: technology and/or processes can be optimised. While the first option mainly aims to reduce the average demand of energy or material, the second approach usually focuses on reducing the process time.

In injection moulding, which is the most relevant manufacturing process for automotive plastic parts, electric energy is the most important source of energy. Electric energy can easily be provided and allows fast production cycles. The main drivers for energy consumption in injection moulding are the injection moulding machine, the cooling system, the material dryer, and the take-out-system (e.g. robot or handling system). Other sources of energy, e.g. Pressurised air for take-out systems, are in most cases originally provided by using electric energy. Fig. 1 shows exemplary how energy consumption is distributed between the different process components. Therefore, it is reasonable to focus on electric energy as a parameter for energy efficiency for the case of injection moulding. Since the desired outcomes of the process are plastic parts, a good key performance indicator (KPI) for energy efficiency of an injection moulding processes is "electric energy used per ok-part".

It is thereby important to emphasise the "ok-part". Especially when looking at processes demanding high quality, the scrap-rate must not be neglected. Scrap usually means that energy and resources get lost (including pre-processes). It is a main driver for energy consumption. The scrap related energy consumption must be integrated when calculating the energy used per "ok-part". Therewith, it can be assured that the KPI is comparing the desired outcome of the value-creation with the entire amount of used energy. Obviously, the technological level of the injection moulding machine used for the production has a significant impact on process performance and energy efficiency [3,48].

Besides technological aspects, the machine operator remains a key factor for efficient moulding processes. The operator's goal is to set up stable and efficient processes for a specific combination of mould and machine. Considering machines and moulds as existing equipment, the key to an energy efficient production processes is combining the components (injection moulding machine, injection mould …) in a way that minimises the target function "energy use for production programme".

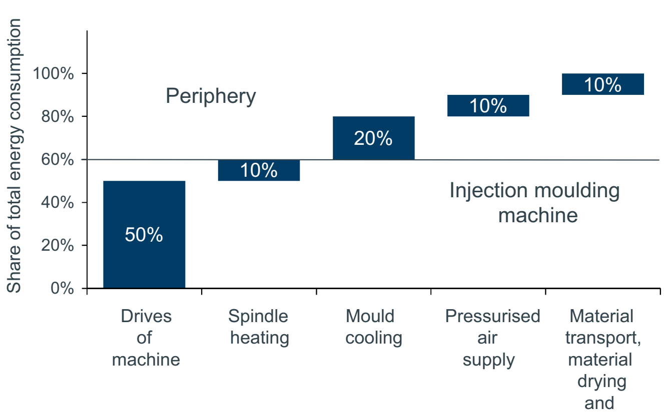

Fig. 1. Exemplary distribution of energy consumption for the case of a hydraulic injection moulding machine [38].

2.2. Energy efficient injection moulds

In injection moulding, the use of plastic material has a huge impact on the total amount of energy needed. Material usage is mainly related to the design of the plastic part, but it is also influenced by the injection mould. As stated above, the scrap rate is a major factor for unwanted material usage. It is generally driven by material, process, mould and part requirements. Considering that part requirements and plastic material are defined, the remaining parameters influencing material usage per "ok-part" are:

- *Process*. When parts are produced with a specific injection mould, the shot weight is already defined. At production level, material usage can only be influenced by minimising scrap rates and – if possible for the plastic material processed – the reuse of scrap material.
- *Injection mould*. The design of the mould has a direct impact on material usage.
  - Depending on the number of cavities and the designed injection system, shot weight can be higher than part weight due to gates and cold runners, which are only required to transfer the melted material into the cavity. Mould designs using hot runners and – if possible – direct gating help saving material for such sprue related elements.
  - Tolerances in wall thickness of a plastic part can lead to additional material usage; such tolerances are related to the geometry of the mould. For decorative plastic parts with a nominal wall thickness of e.g. 3.0 mm, a tolerance of +0.2 mm is usually allowed. If the mould makes full use of the allowed tolerances, the material usage per part will be increased by more than 6%.

Furthermore, the scrap-rate is directly linked to the parameters "dimensional accuracy within given tolerances", "mechanical properties of the plastic part" and "required surface appearance". Each of these parameters is directly linked to the mould itself. The characteristics of the mould are essential to meet the quality goals in order to avoid scrap (of course, material and process remain as sufficient prerequisites). Regarding dimensional accuracy, an efficient mould should be designed and "tuned" in a way that all functional measures relevant for part quality are adjusted to the middle of the given tolerance zone. Like this, any process-related deviations can be compensated for best, as such a "tuned" mould allows bigger process related tolerances compared to a mould not being tuned. Scrap rate due to dimensional issues will thereby be minimised. A balanced heat removal from the mould is important to avoid unwanted warpage of the part. The cooling system of the mould is therefore a key factor for uniform shrinkage and for avoiding warpage.

Mechanical properties of crystalline plastic material are highly dependent upon the cooling process [54] and are therefore linked to the temperature distribution and heat transfer capacity inside the mould. The cooling system and the material used for the cavities of the mould are the main mould-related factors.

The visual appearance of a part surface is strongly influenced by temperatures of the mould surfaces. Locally inappropriate temperatures on the cavity surfaces can cause scrap due to local visual imperfections such as a (locally) wrong level of gloss.

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