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New Approach for the Efficient Attainment of Flame Retardancy Using Multi Component Injection Molding

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Abstract. The injection molding process yields many possibilities to create innovative plastic part solutions. Based on extensive research in distinct subject areas and the cross-disciplinary interconnection between different academic disciplines lately an interesting new approach for the efficient and effective attainment of flame retardancy could be identified: Multi component injection molding, where two or more plastic melts are injected next to or within each other during one cycle, can be used to produce innovative flame retardant plastic parts. These parts have an optimized skin/core structure with the core part consisting of the pristine polymer while the flame retardant polymer system is located in the skin. Such a structure proves to be ideal, because it allows for a faster protection dynamic.This broadening of the field of application of standard injection molding machines is made possible by the use of intermediate plates with individually suitable modular technological inserts. The modular inserts required for this kind of application comprise hot runners including shut off and control functions to separate and join melt flows from different injection units into one cavity. These modules make for the combination of the sequential and simultaneous injection of melts. In that account first trials which prove the concept to be viable have been conducted. Promising results will be shown as well as the principles of laboratory and industrial scale implementation of the underlying production process, while further research still is ongoing. In conclusion the paper will point out the advantages, possibilities and application potential given by this new approach. Cost savings will be given by the supersession of costly special machinery as well as achieved material savings and increased part quality and process stability.

INTRODUCTION

Small engineering companies as well as research institutions are facing innovation push and pull and its highs and lows all day every day since decades. Modern engineering always is a trade-off between efficiency and flexibility, since market requirements are becoming more and more volatile and still constraints are tight. Having the finger on the market steadily will consume a lot of valuable resources and simultaneously is a prerequisite for the generation of long term revenue. So market sensitivity should not come at any cost, just as well as efficiency should not cut short flexibility. Innovative engineering solutions have to strike the balance between sufficient market compliance and reasonable costs, and aim at so-called agility.

This paper will show in the first section the first insights from the development of a new approach for systematic innovation engineering to promote agility enhancement. The creation of such an approach is motivated by the necessary efforts to let market requirements be met by research and design processes. Further the paper will point out the particular market requirement for new flame retardancy solutions and the associated research challenges. In the third section an innovative solution to meet flame retardancy demands will be shown. Within the forth section the description of the experiments and results leading to this solution will be given before in the last section conclusions will be drawn as well as a short outlook given.

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PLASTIC PART SOLUTIONS FOR AGILE INDUSTRY APPLICATION

An ongoing research project studies how it is possible to target industry relevant findings during research and creative processes proactively using given resources and core competencies to meet prioritized demands. The rise of modern methods and new standards allows for the use of the given data accumulated during engineering and research processes. The arising technological possibilities brought along with digital process support and data mining possibilities give way to match the wide range of innovation potential with actual necessities within the market. This allows for broadening the view and for moving away from the point of maximum efficiency and minimum requirements. This proactive approach may lead to a loss of efficiency and risen cost during the early phases of development. Meanwhile it will lift the developed solutions to the area of agile innovation proposition striking the balance between sufficient market compliance and reasonable efficiency.

As revenue equals application units multiplied by their value at the point where supply and demand meet, scaling the supply curve to fitting additional demands will nurture new fits and therefore let the revenue rise to the sum of those values. Scaling the innovation fits perfectly along the demand curve will even lead to revenue in the amount of the integral underneath the curve. To make this possible several methods of business informatics can be used to extract, collect and analyze data, emulating variability and evolutionary processes during product development and research processes [1, 2, 3].

The use of standard operations research methods, heuristics and optimization algorithms will then outline new fits of necessities stemming from market requirements with the given product scope. Of course as market requirements are volatile the scale of supply efforts leads to the necessity of modifications within the means of production. Modification expenses in plant machinery will be significantly higher if extensive changes are necessary within the core parts of the machinery itself. Interchangeable components yield less expensive flexibility potential and added inserts will do even more so. This is why in a lot of specialized application cases A&E technological inserts are used to equip standard machinery, transforming it into the perfect machine for the specialty method needed. One typical example for an added on specialty method which is often applied to standard machinery is sandwich injection molding while one way of the market changes to present themselves stand by as the altered requirements for flame retardancy.

FLAME RETARDANCY INNOVATION AS AN INDUSTRIAL REQUIREMENT

There is a steadily growing amount of electronics housed in plastics while also in sectors like transportation, building and furniture polymer materials can only be used when fulfilling fire retardant standards. The market volume of flame retardant chemicals is supposed to rise from 1.7 million tons in 2007 and 2.5 million tons in 2017 to over 3.7 million tons in 2022 [4].

Additionally new European regulations are progressively restricting the use of halogenated fire retardants, thus having an impact on the consumption of flame retardant additives due to obligations for manufacturers concerning health and environmental compliance. These facts have lead towards a pressing demand for a reduction of the fire hazard posed by highly combustible polymer materials. Therefore intensive efforts are being made to develop new safe and economical fire protection approaches [5, 6, 7].

The common approaches can be categorized into three types: The first type is the mechanical incorporation of flame retardant additives into the bulk polymeric matrix. The second possibility is to bind flame retardant chemicals to the matrix as integral part of the polymer chain forming functional groups. The third type is stated by surface modification. It stands to reason that this is a very convenient, economical and efficient way to protect substrates against fire, because of the ’paramount role played by the polymer surface during combustion’ [5]. Placing the flame retardant chemicals at the surface proves to be ideal, because it allows for a faster protection dynamic. The heat penetration and diffusion to the gas phase occur at the polymer surface, so that the chemical and physical characteristics of the surface affect the ignition process predominantly.

During the recently conducted research project *PHOENIX* aiming at the development of compounds with new nanoparticle flame retardant additives one aspect of consideration was how to save valuable nanoparticle specimen material. Of course it was a reasonable attempt to use the flame retardant nanomaterial compound within the surface layer only, leaving the inner bulk material plain. This was realized by the formation of a layer structure during the injection molding process as described in the following section. Not only did it turn out to be advantageous because of the reduced amount of necessary flame retardant material but also resulted in a highly efficient way to protect the substrate which constitutes an industrially implementable highly productive one shot solution.

EFFICIENT REALIZATION USING MULTI COMPONENT INJECTION MOLDING

The variable configuration of standard injection molding machines using intermediate plates with individually suitable modular technological inserts was rendering possible the trials during the research project and at the same time gives way for the industrial use of the new approach. Sandwich injection molding is an injection molding process for the production of parts with a skin and core structure. The melt for the skin is injected first. Whereas the core material is injected subsequently, pushing forward the skin component. The skin material completely covers the core material in the final part if the determining injection parameters like material ratio, injection speeds, injection temperatures or mold temperature are properly set. Using a sandwich valve of two axially positioned pistons, which must be manufactured with very small tolerances, and ensuring the clean separation of the two different melt streams is essential [8].

Test series were conducted to minimize wear and optimize the process. The specimen production was realized using a 100t clamping force two component injection molding machine which was equipped with a 2C intermediate platen as an added technological insert (working principle shown in figure 1).

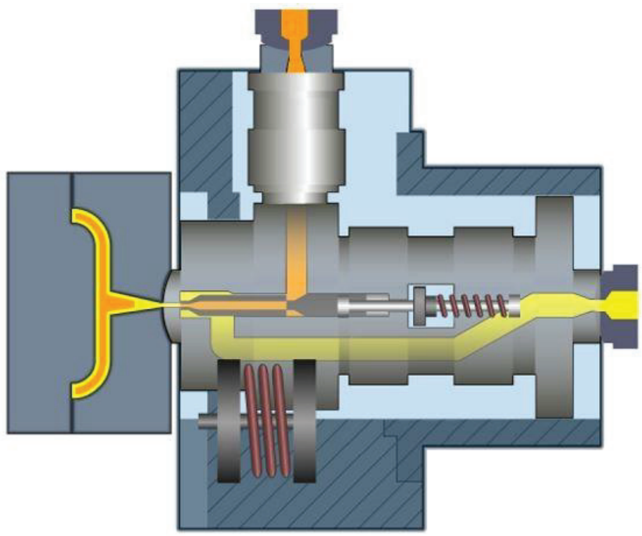

FIGURE 1. Scheme of the technological insert, an intermediate platen, used for the experiments

NEW APPROACH FOR ATTAINMENTOFFLAMERETARDANCY

Pursuing the intend to find effective flame retardant compounds trials were conducted concerning flammability parameters. During these trials very interesting findings were obtained: Flame retardant skin layers protected the specimen from burning nearly as well as the flame retardant protected the specimen if added throughout the complete plastic part. The core component was formed of pure Polypropylene (PP) *Moplen HP500N* while for the skin component various compounds were tested. Trials with a skin layer of a flame retardant composite with 25% *Exolit 766*, as well as of a flame retardant PP copolymer with 25% *Budit* (*Dinaplen PPC 1525*) in matrix of PP *Moplen HP500N* were conducted with various skin layer thicknesses in the range of 0.4mm...0.6mm while the core layer thickness ranged from 1.8mm...2.0mm. Additionally specimen of High Impact Polystyrene (HIPS) were prepared with skin layer thicknesses ranging from 0.5mm...0.8mm containing an intumescent additive and nanoparticle flame retardant additives. The injection parameters and the mold temperature were varied in order to achieve thin but uniform skin layers. The most important process parameters besides the melt temperatures of the skin and the core component are the shot volumes of the two injection aggregates, the respective injection speeds, the injection time as well as the delay between the first and the second shot.

The samples were evaluated by mass loss calorimetry (MLC) at *ENSCL* using a Mass Loss Cone of 35kW and 35mm. The formulations are listed in table 1 and the results are presented in tables 2 and 3. The PP trials showed a reduction by 65% of the peak heat release rate (pHRR) value of the sandwich samples compared to the pristine PP samples. The HIPS trials showed a reduction by 44% resp. 54% of the peak heat release rate value of the sandwich samples with a skin thickness of 0.5mm resp. 0.8mm compared to the pristine HIPS samples. The specimen with a flame retardant surface layer showed an equally satisfying performance as plates made from pure PP/*Exolit* composite confirming their applicability for flame retardancy requirements. The concept of multilayered plastic parts prepared by sandwich injection molding in order to form a fire retardant protective skin layer is therefore validated and should be considered for further applications.

TABLE 1. Formulations of sandwich injection molded samples

Specimen	Material abbreviation	Description	Result
Pristine	Ref PP	Neat PP plates made from *Moplen HP 500 N*	pHRR reference without flame retardant (FR)
Pristine with halogen free FR	3,3,1-2-1	Plates made of *Moplen HP 500 N* + 15% Mg1	The incorporation of 15% Mg1 in PP only permits a slight reduction of pHRR (24%).
Sandwich with FR in the skin	4,5-4J	Sandwich plates made of *Moplen HP 500 N* as core and *PP copolymer Dinaplen PPC 1S25* with 25% *Budit* as skin	The sandwich sample (4.5-4J) exhibits a 65% HRR reduction and an intumescent layer is formed at the surface upon testing.
Pristine with halogen based FR	PPC Dinaplen	Plates made from PP copolymer *Dinaplen PPC 1S25* with 25% *Budit*	pHRR is dramatically reduced (by 92%) for the non-coextruded sample (PPC Dinaplen) thanks to the development of an intumescent coating

TABLE 2. MLC data of FR PP-based sandwich injection molded samples

Indicator	Unit	Ref PP	3,3,1-2-1	4,5-4HJ	PPC Dinaplen
t_{ign}	s	68	57	32	53
t_{fout}	s	704	877	1333	1642
$t_{flaming}$	s	636	820	1301	1589
pHRR	kWm^{-2}	388	296	136	31
t_{pHRR}	s	157	195	307	61
THR	MJm^{-2}	95	90	79	10

CONCLUSIONS

During an interdisciplinary research project a new approach for the efficient and effective attainment of flame retardancy could be identified. The growing request for flame retardancy solutions which are safe and complying with health as well as environmental standards should be met by a proactive industry supply increase. A still progressing research attempt focuses on the targeted innovation development for such urging demand scenarios within research projects and small engineering companies including the economical potentials to be gained as a consequence. By the special multi component injection molding method of sandwich injection molding a skin and core layered structure can be created. Furthermore this processing method can be added to standard machinery by variable configuration using intermediate plates with individually suitable modular technological inserts giving way for the flexible industrial use of the new approach.

The results show a significant decrease of the amount of flame retardant chemicals necessary to obtain satisfying flame retardant behavior by pursuing the approach of a skin and core layered structure of the specimen. The PP trials showed a reduction by 65% in the peak heat release rate (pHRR) value of the sandwich samples compared to the pristine PP samples. The HIPS trials showed a reduction by 44% resp. 54% of the peak heat release rate value in the sandwich samples with a skin thickness of 0.5mm resp. 0.8mm compared to the pristine HIPS samples.

TABLE 3. MLC data of FR HIPS-based co-extruded samples

Indicator	Unit	Ref HIPS	0.5mm	0.8mm
t_{ign}	s	115	88	135
t_{fout}	s	860	767	797
$t_{flaming}$	s	745	679	662
$pHRR$	kWm^{-2}	350	197	159
t_{pHRR}	s	212	241	294
THR	MJm^{-2}	71	50	49

Necessitating the sandwich injection molding process it is possible to obtain an industrial scale implementation of flame retardant surface modification at reasonable cost. Economical advantages will be given not only by the achieved material savings but also by the supersession of costly special machinery as well as an increased part quality and process stability. Following the possibility to produce the layered structure within one single production step with no additional coating machinery and handling needed, the repeatability within a stable production process increases part quality and safety while it decreases the risk of delamination as the skin layer forms an integral joint of the material within the part. In conclusion the presented solution comprises an affordable and satisfying response to the current flame retardancy challenges for standard injection molded parts.

Nevertheless further reaching trials should be conducted to find the best possible formulations and material combinations to optimize flame retardancy performance as well as relevant part characteristics like for example mechanical properties. Likewise the conceptualization of systematic research should be addressed in growing intensity, giving more weight to the anticipatory point of view targeting demand relevant and foresighted application development.

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