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DIESEL EFFECT PROBLEM SOLVING DURING INJECTION MOULDING

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ABSTRACT

Study describes principles of diesel effect creation during thermoplastic injection moulding as a consequence of wrong injection conditions and poor venting system design. On real example, study shows sequence of all steps to eliminate this sort of material degradation with minimal costs in phase when mould is already made. As a first, process parameters were optimized by CAE simulation to minimize cavity internal gasses creation. Finally the specific mould modifications were suggested to improve the effectiveness of venting system.

KEY WORDS

Diesel effect, burning marks, venting of injection moulds

INTRODUCTION

In most cases, thermoplastic product quality is not determinated only by geometrical and dimensional accuracy or mechanical properties. Visual aspect of part can be as important as its operational properties. But often in an effort to reach best appearance of the plastic part, designers do not pay attention to importance of correct determination of some significant mould components, which finally can result just in opposite effect. But when problem shows, it can be too late for changes. For example in case, when poor mould cavity venting system was designed.

MOULD CAVITY VENTING

Injection moulding of thermoplastics requires the material to be melted by heat and then to be injected into a closed mould cavity at high pressure and velocity. As it enters the cavity, the melt must displace the gasses trapped inside the cavity at mould closing time. If these gasses are not expelled from the cavity, they could suddenly compress between 2 and 5% of the original volume, causing additional high pressure inside the cavity. This high pressure increases the temperatures well above those suitable for the injection moulding process. These elevated

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temperatures cause local ignition (diesel effect) of the thermoplastic melt and burning of the moulded products (1).

The escape of gasses from mould cavity is allowed by venting system. The venting system is created by gaps in cavity parting planes, mould cavity insert parting lines, ejector pins, ejector rings, sintered porous insert plugs or special active venting systems as logic seal (negative coolant pressure) mould venting, cavity vacuum venting systems and other.

But venting is normally a minor aspect of mould design, which is frequency neglected until moulding trials indicate mould inadequacies related to venting. An understanding of the purpose and function of vents can assist the mould designer to design vents where clearly needed and ensure that the mould may accommodate additional vents when required (2). When venting system is inadequate, following consequences are occurred:

- burn marks causing a phenomenon known as dieseling,
- short shots as a result of the inability to fill the cavities completely,
- internal gas voids found in thicker wall sections,
- poor weld lines of divided melt streams,
- poor surface or rough finishing caused by the inability to fill cavity quickly,
- decrease of mechanical and chemical resistance by material degradation,
- longer moulding cycles caused by higher melt/mould temperature (1),
- higher injection pressure necessary,
- surface defects through detachment of the polymer from a mould wall,
- abrasion and corrosion mould material by aggressive gases (diesel effect),
- mould coated by combustion residues in the combustion gas (diesel effect),
- mould repairing and maintenance costs, short service life, etc. (3),

Since a lack of venting is associated with several significant defects, many large vents are desirable at different locations. However, if a vent is too thick, then the polymer melt can seep out of the vent, causing a thin but sharp line of plastic flash to form at the vent locations. In many moulding applications, this flash needs to be trimmed by the machine operator using a deburring tool. Such deflashing is undesirable since the operator incurs another cost. (2) There are several empirical relationships how to define cavity parting plane gap size, but the exact dimension that would be ensure sufficient cavity venting without flashing marks on visual surfaces cannot be calculated. Solving this venting problem in time, when mould is already made and another significant costs for mould redesign are not acceptable was demonstrated on electrical plug from automobile. Figure 1 shows a reject with thermal degradation of material in front of part.

Fig. 1 *The reject with material degradation caused by diesel effect*

PROBLEM DESCRIPTION

The plug is encapsulation of two conductors into thermoplastic PBT with 15% GF, already implemented into production. In front of plug is a fillet, which is a restriction for placing of venting pins. Just this fillet is location of burn mark. The plug has got several cavity parting planes on outer surfaces. Flashing marks are unacceptable at this faces. A new solutions to solve inadequate venting system problem of plug with minimal costs or production times had to be defined.

INJECTION PROCESS PARAMETERS VERIFICATION

The purpose of venting system is to ensure escaping of air trapped in cavity at closing time. But in some cases when the melt is overheated at high temperature, another gasses can be created in cavity during injection and volume of closed gasses is increased. The faster the melt is injected into cavity, the higher is the pressure of compressed gasses and thus higher temperature is generated. For verification of process conditions CAE analysis was realized in Moldex3D Solid solver. The analysis will show also accurate locations of entrapped air. Figure 2 shows the last filled space in cavity, calculated by simulation.

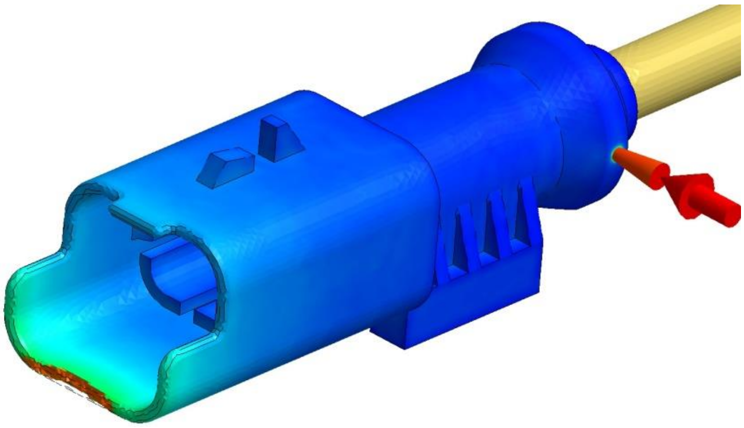

Fig. 2 *The last filled space in cavity detected by FVM CAE simulation*

Available material sheets did not include all of material properties needed for simulation. Therefore melt flow rate index (MFR), melt volume rate index (MVR) and viscosity vs. shear rate functionality were measured on capillary rheometer Dynisco LCR 7001. The viscosity vs. shear rate functionality behaved according to Modified Cross viscosity model. The recommended melting temperature of used material was 240 - 260 °C. Producer was heating melt to 260 °C. Plug was injected by hot runner with gate size about 1 mm diameter and filling time 1,3 sec. As results of simulation shown, there were generated high shear rate in material due to melt compression in runner gate. Max. allowed shear rates for PBT are 50000 sec^{-1}, the generated shear rates were 67000 sec^{-1}. As a result of this the melt was overheated to 284 °C. The overheating of used material to this temperature can lead to additional gassing or thermal degradation of polymer. Figure 3 shows temperature fields in 1 sec during filling, where max. value was measured. Considering this fact, decreasing of melting temperature was suggested.

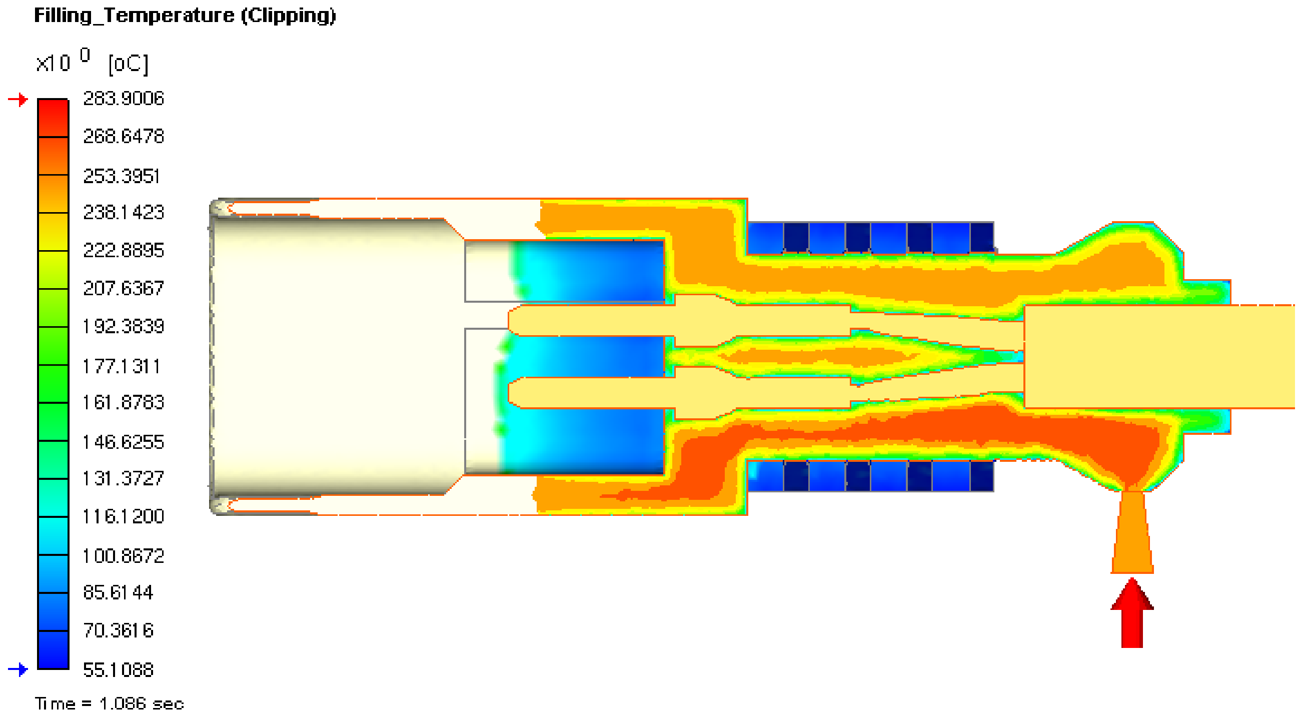

***Fig. 3** Temperature fields in melt during filling in 1 sec (longitudinal cross-section view)*

The animation of cavity filing also helps to predict melt flow behaviour. The time when melt flows from full to tapered cross-section in 84 % of filling was detected and according to this result, two screw velocity profile was suggested in specific times. The time of switch from filling to packing was suggested in 95 % of filling. This way more uniform flow of melt front was achieved and in addition the air has more time to escape.

From other results, melt front temperature, shear stress, pressure in sprue and required clamping force were studied. From the study of required clamping force diagram there was suggested to minimize size of this force until 1 sec of filling. This way gasses compressed to high pressure in cavity can partially unclench mould and escape.

MOULD DESIGN REVIEW

The air leakage from original mould was realized just by cavity parting planes. Capability of gasses to escape from mould cavity is not dependent on cavity parting plane gap size only, but also on size of areas in parting plane gaps which escaping gasses have to pass around. Gasses can be closed just in cavity or anywhere between surfaces of mould parts in cavity parting plane. As figure 4 shows, cavity parting planes of original core used in production was created by simple faces. On these faces, black burning marks can be seen as a result of escaping gasses dieseling during manufacturing. Therefore, the mould parts must be cleaned regularly. In the core, there are two holes for part inserts and four ejector pins embedded. These features inhibit insert of another venting pins.

In Moldex3D user can realize venting analyses too. The results of this simulation are the temperature and pressure of trapped gas during filling. But the accurate value of recommended cavity parting plane gap size (hundredths of a millimetre) computed by analysis cannot be finally made or measured, so the results cannot be applied.

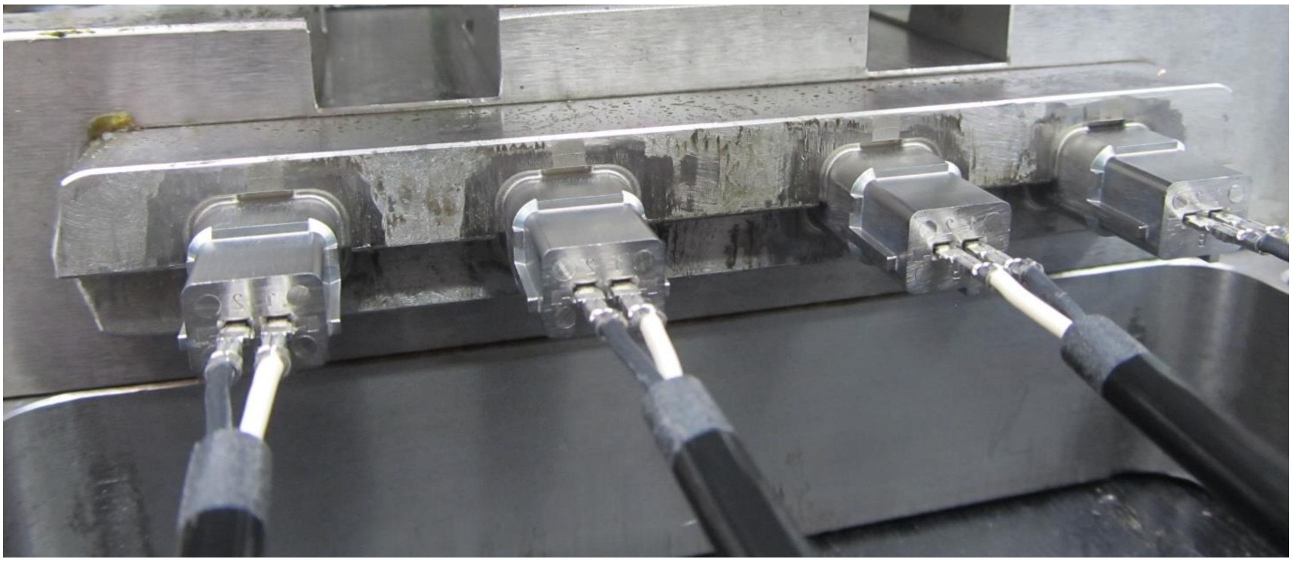

Fig. 4 *The original core of mould used in production*

In order to avoid flashing the size of parting plane gaps were not enlarged, but only the specific mould modifications was suggested. Figure 5 shows CAD model of core with auxiliary venting channel. The channel is milled near to critical location of burning marks. This solution narrows cavity parting face the compressed gasses have to pass around. If venting channel will not be sufficient, it can be connected with cavity by little scorings made by marking laser. Channel can be made in several forms. Also with chamfer on cavity-venting channel intersection.

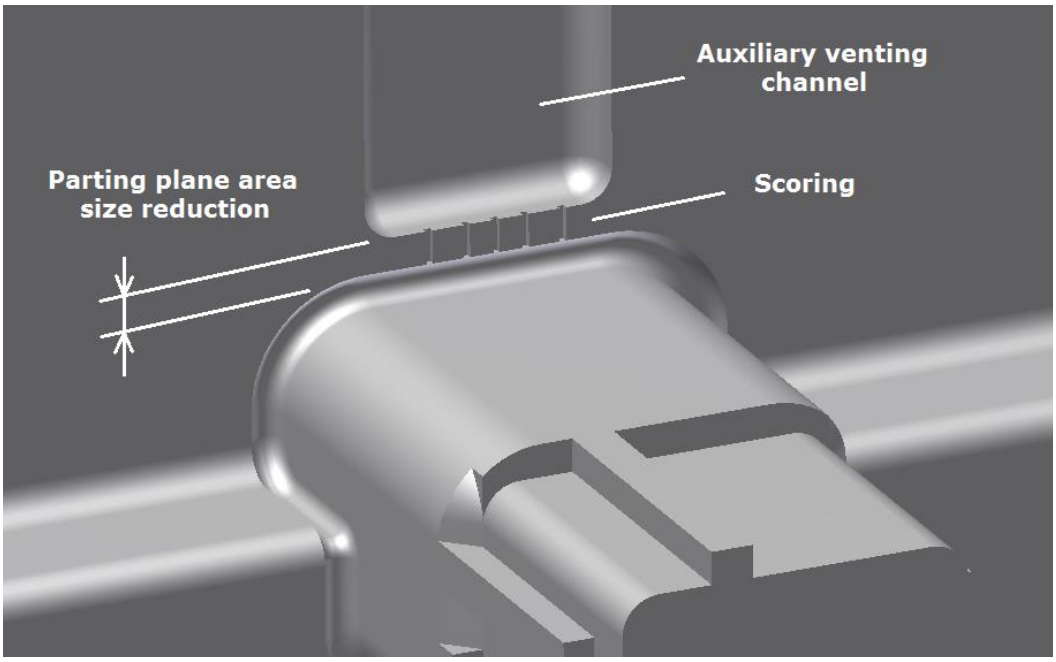

Fig. 5 *Core with auxiliary venting channel - one of suggested solutions*

If suggested injection process parameters changes and mould modifications are not sufficient, there is a need to redesign the mould. In this case, cavity parting planes must be added or special venting systems used.

Designers should review part geometry also. Fillet in front of plug is not necessary feature for part proper function. If fillet was removed, cavity parting plane could be transferred to the edge of part. This way possible flashing in cavity parting plane would not be so visible and manufacturing can be simplified significantly.

CONCLUSION

The diesel effect (dieseling) is undesirable phenomenon causing thermal degradation of thermoplastic material during injection moulding. Prediction of this effect can be very difficult and the real efficiency of venting system shows during first mould test in time, when it is too late for changes. In this study, on real example the whole procedure of diesel effect elimination was demonstrated with minimal costs in phase when mould is already made. As the solution injection conditions were optimized with CAE simulation. Then the original mould design was reviewed and specific modification of mould suggested.

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