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SILVER STREAKS ON SURFACE OF INJECTED THERMOPLASTIC PARTS

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Abstract

Silver streaks on injected thermoplastic parts are the undesirable features, considered as a visual surface defect. If they appear, elimination of this technological problem can be very difficult, especially in case the cause of their occurrence is not actually known. In this study, the detailed analysis of silver streaks formation was carried out. At first, the defect was microscopically studied. Then, the several analyses were performed to find the cause of silver streaks formation. Finally, solutions to the problem and elimination and this kind of surface defect were suggested.

Key words

injection moulding, silver streaks, moisture in polymer granulates, air bubbles

INTRODUCTION

There are several kinds of surface defects on injected thermoplastic parts. According to the causes of their formation, the defects can be caused by incorrect part design (sink marks, cracking), poor mould design (flashing, burning marks, visible weld lines) or unsuitable production conditions and polymer granulate preparation (flow marks, gels, crawling, pinholes and others). Most of them are well known and described. However, in some cases, source of the surface defects may not be obvious, and while technologists focus on the elimination of its supposed cause, a real problem can be hidden just anywhere else. In such cases, a more detailed analysis is needed.

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PROBLEM DESCRIPTION

The silver streaks were observed on the surface of a thermoplastic cover (Figure 1), made of PA6 polyamide with 20 % glass beads and 10 % glass fibres in weight ratio. In the Figure, the defect is marked by a red ellipse.

Fig. 1 *A plastic cover (reject) with silver marks*

Streaks looked like a cluster of reinforcing fibres on the part surface in thick-walled areas and the areas around the cavity gate. The defect looked like a narrowed short silver lines, oriented in downstream of the plastic melt. To verify the assumption that streaks are not consequence of fibres clustering on the part surface, the specific areas were scanned with Zeiss Axio imager 2 microscope in both polarised and non-polarised lights in various magnifications. The following figures compare the part surfaces of the clean area without silver lines (Fig. 2) and the reject area with silver lines (Fig. 3) in non-polarised light.

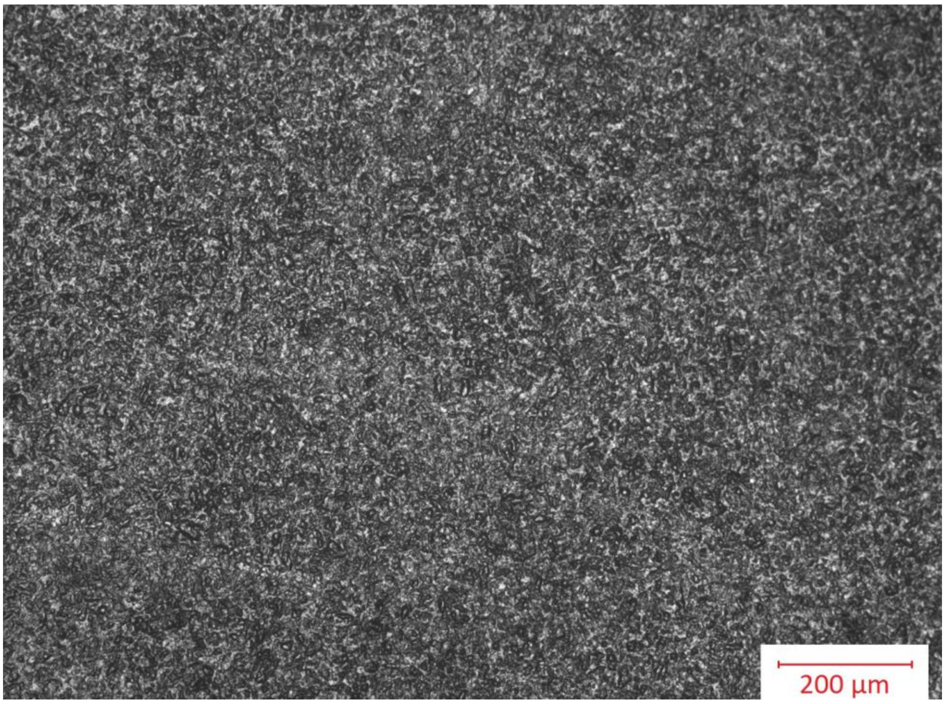

Fig. 2 *Part surface of the area without silver marks*

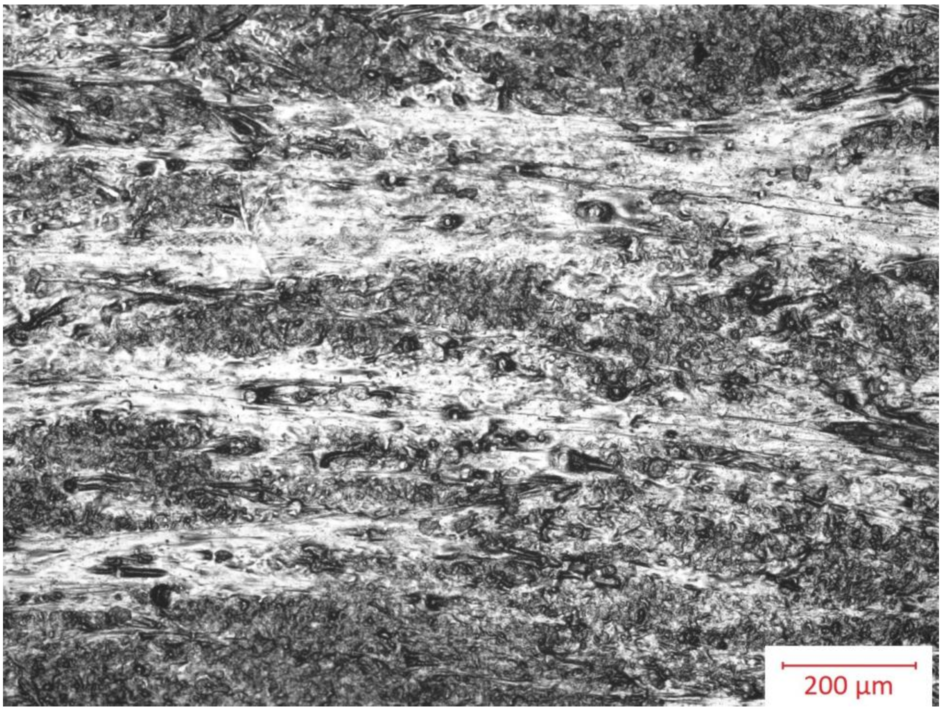

Fig. 3 *Part surface of the area with silver marks*

As shown in Figure 3, although glass fibres and beads were visible on the surface, it was not their clustering. The observed sort of marks on the reject areas is typical for moisture, air bubbles or depredated particles in the polymer melt.

Moisture in polymer granulates is considered as the main reason of its formation. Plastic materials absorb a certain degree of moisture during storage. If the material is not dried properly before moulding, the moisture residing in the resin evaporates and turns into a steam during the injection process and splays on the surface of the moulded part. Also, during the plasticisation period, a certain amount of gas can be trapped and blended into the melt material. If the air does not escape during the injection process, it could splay out on the part surface. Marks of such origin are also accompanied by the dimples on surface. Contaminants and old degraded material particles which are charred during moulding can be the third cause of marks of this type. Burning particles generate additional gases which are subsequently splayed out on the part (1).

PRODUCTION CONDITIONS ANALYSIS

Polyamide 6 used for production is generally a highly hydrophilic material. Before its moulding, strict drying conditions must be observed. Therefore, moisture of material granulates used directly in the injection process was measured. Granulates were additionally dried for 25 hours at the temperature of 80 ºC (more than the producer recommends) in a dryer different from that used in production. Subsequently, these were naturally cooled in desiccators. Measured moisture of material was 0.08 wt. %, which is a negligible and satisfactory value that should not induce silver streaks. In general, the material with moisture lower than 0.2 wt. % is considered dry (2). As the measurement confirmed, drying conditions during manufacturing were sufficient, so it was necessary to look for the cause of silver marks formation somewhere else.

Water can also condense in the mould cavity surface, in injection system, in injector machine granulates reservoir etc., from the ambient air humidity. However, detection of this phenomenon can be very difficult and often impossible.

In the next step, the production conditions of the applied injection process were reviewed. Verification started with FVM CAE analysis in a simulation programme. Although all of the material properties needed for simulation were not known from the material datasheet, these were measured additionally. The melt flow rate index (MFR), melt volume rate index (MVR) and viscosity vs. shear rate functionality were measured on Dynisco LCR 7001capillary rheometer. While measuring, an interesting phenomenon was observed. According to datasheet, the recommended melt temperature of the material is in the range of 270 - 290 °C. The applied melt temperature during injection was 270 °C, which was the bottom value for melting. During measuring viscosity at this temperature, air bubbles were trapped in the melt very significantly. The melt was very dense. It required longer homogenisation times and, what is most important, it required "venting times". These were the only times, when waiting for the air escaping from melt. A small content of air bubbles contained in the melt during the measurement can be also observed in the resulting graph in Figure 4. The first measurement point is out of the result curve. This represents a measured error caused by air bubbles in the melt, which are the most probable source of the silver streaks formation.

As observed during viscosity measurement, the set melting temperature appeared to be low. As the graph in Figure 4 shows, the measured melt viscosity was not too high, but the increase of melting temperature could help gases better escape from the melt, and also reduce the melt homogenisation time. To verify suitability of the melting temperature increase, CAE analysis was additionally done.

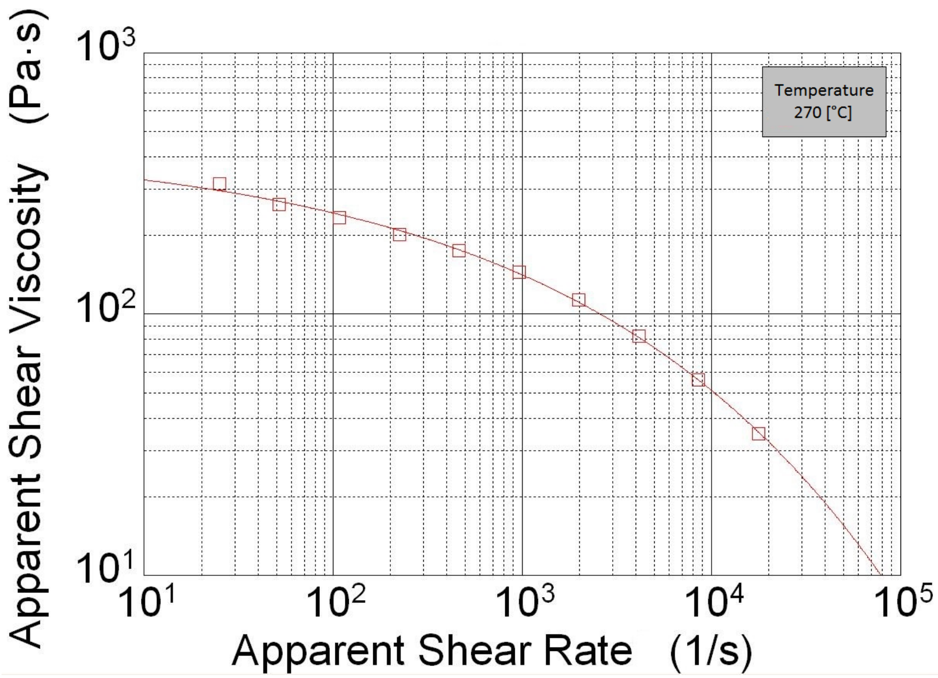

Fig. 4 *Measured shear viscosity vs. shear rate functionality*

At first, FVM CAE analysis with the real production conditions was conducted in Moldex3D Solid. The melt was injected by the hot runner system with temperature 270 ºC and the gate of about 1mm diameter in size. As the results of cavity filling showed, during injection process, the high shear rates were generated in the cavity gate. In general, the maximum recommended shear rates for polyamide 6 are 60 000 s^{-1}. However, the shear rates generated during injection achieved 130 000 s^{-1} according to Moldex3D results. As a consequence of the high shear rates generation, temperature of melt increased to the value above 295 °C. In Figure 5, temperature fields in the cross section of cavity are plotted in time 0.5 second of filling. The red arrow indicates location of gate of the hot runner system. The melt temperature increase explains, why initially apparent low melt temperature was finally sufficient during injection

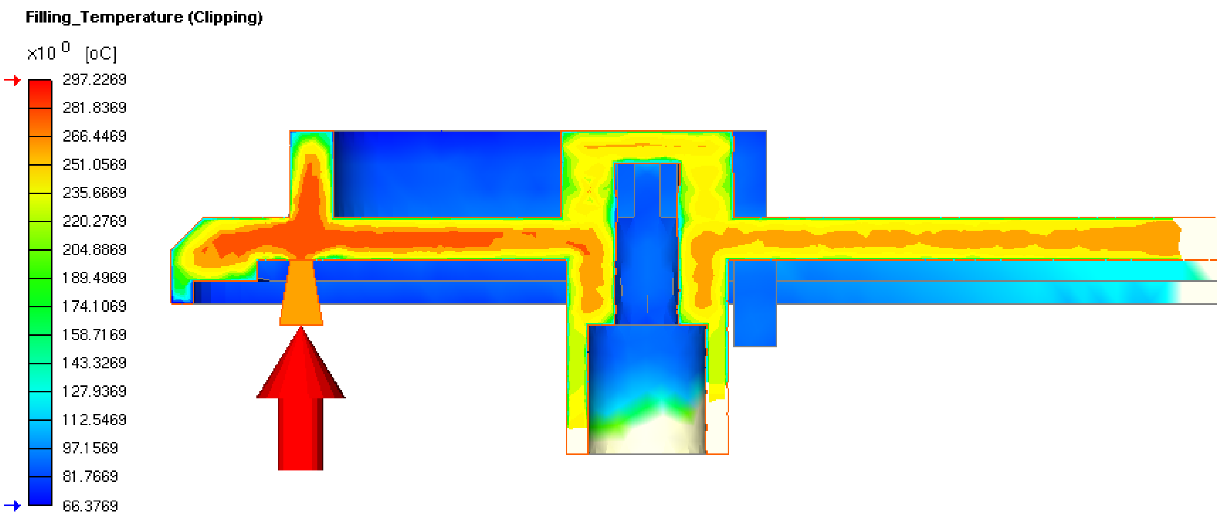

Fig. 5 *Temperature fields in cross section of cavity during injection*

DISCUSSION

Moisture in plastic granulates is usually considered as the main reason of silver streaks formation on a thermoplastic part surface. Typically, it is moisture, which granulates gain during cooling phase in production, or during storage from humidity of environment. The water in plastics can be absorbed by the additives (especially by talc) or own hydrophilic capability of the polar thermoplastics (especially polyamide). Next, gasification of the water is caused due to heating granulates in melting phase. The generated gas bubbles are agglomerated on the melt front and splayed out on the part surface, where they create silver marks. This kind of the surface defect usually shows, when the drying of granulates and cleaning of moulds are not sufficient before processing.

In this particular case, the cause of silver marks formation was hidden somewhere else. The content of moisture measured in the granulate used directly in the injection phase was too low to form such significant marks. Defects were formed during the whole production time, and also after the mould parts were cleaned. In the cases when a source of the silver marks generation is not exactly known, the technical studies have recommended modifications of several injection parameters to eliminate the marks, such as to;

- decrease the melt temperature,
- decrease the nozzle temperature,
- raise the mould temperature,
- shorten overall cycle,
- relocate the gate and others.

To verify the suitability of the changes in injection conditions, CAE analysis was suggested. Therefore, the unknown material properties needed for simulation were measured. In this phase, the cause of silver streaks formation was detected randomly. While measuring material viscosity, a significant closing of air bubbles was observed in the plastic melt. The presence of air in a melt is usual. While mixing the melt, the air bubbles are escaping. Since the temperature of melt was too low and the melt was too dense, the bubbles were trapped. To remove this effect, longer homogenisation times are recommended. However, the solution of a longer production cycle is not usually acceptable. Although many studies have recommended decreasing the melt temperature in order to minimise the silver marks formation; the elevated melt temperature was recommended just to facilitate the escape of air bubbles. Therefore, CAE analysis was carried out. Its aim was also to investigate why the relatively low melt temperature observed while measuring viscosity was not low during moulding.

As the results of the simulation show, high shear rates generated in melt during injection significantly increased the melting core temperature. Since additional preheating of the melt can generate more gases in the cavity, the increase of the initial melt temperature was not recommended. As a solution to the silver marks elimination, the following procedures were suggested:

- increasing the gate size (to decrease shear rates),
- increasing the melting temperature,
- increasing the cavity filling time,
- increasing the melt homogenisation time,
- increasing the mould temperature.

It is necessary to reduce the achieved shear rates not only because of the melt preheating. Too high shear stress caused by high shear rates can lead to the mechanical degradation of material, when molecular chains of polymer (reinforced fibres also) can be strained too much until they tear. In this way, mechanical properties of material are decreased.

Another relative solution, a change of material, can be also applied for less hydrophilic material or material with lower moisture sensitivity. The trapped gas bubbles in the melt that was observed during measuring viscosity can be generated due to the plastic heating, too. In addition, the part that was manufactured is not a mechanically loaded component, so it does not require material with the properties of polyamide 6.

CONCLUSION

The aim of the investigation, the method of silver streaks elimination as a kind of surface defect of plastic part was determined. For exact identification of streaks characterisation, these were microscopically studied at first. Then, moisture of plastic granulates was measured as the most probable reason of their formation. Because the measured content of water in plastics was too low, production conditions, injection parameters and material properties were reviewed. As it was found randomly, streaks were caused by significant gas bubbles trapped in melt during homogenisation. The bubbles were sprayed out on part surface during injection subsequently. Finally, the procedures for marks elimination and defect removal were suggested. The injection process was also optimised.

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