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Chocolate Santas under surveillance

Data loggers in polycarbonate moulds help with process monitoring

To determine the stresses that occur during the chocolate production process, the Institute for Plastics Technology (IKT) at the University of Stuttgart fitted chocolate moulds made by Hans Brunner GmbH with data loggers that deliver information from the production process, making it possible to identify critical loads. This enabled optimisation measures to be developed to ensure the longest possible service life.

Chocolate figurines and bars are produced by using moulds, in which cracks can form under high loads. Data loggers can help to identify critical parameters in the production process © Hans Brunner GmbH

Polycarbonate moulds are subjected to numerous different stresses during the chocolate production process. In addition to the effects of temperature resulting from being filled with warm chocolate and then passing through a cooling zone, such stresses also include high mechanical loads applied both for the purpose of distributing the chocolate within the mould and by the tapping-out mechanism for demoulding the product. Furthermore, a wide range of different cleaning agents are used to remove residues from the moulds before they pass through the process once more. In order to optimise moulds for customers' systems in a targeted way, the research project Inform equipped selected chocolate moulds with data loggers. These detect the stresses that occur during production, allowing appropriate optimisation measures to be developed. The aim was to guarantee a longer service life of the moulds under the existing conditions. The purpose of this article is to highlight the parameters in the production process that may be critical, and to show how these can be identified. The approach developed makes it possible to eliminate these parameters without increasing production time or negatively affecting the product.

Monitoring of process parameters

Since the exact process parameters for chocolate production have hitherto largely been set on the basis of experience and have not been monitored, it was first of all necessary to determine these as precisely as possible. For this purpose, a data logger was integrated into moulds for various different chocolate manufacturers, making it possible to record the temperature, air humidity and 3-axis acceleration during the production process. Because chocolate moulds are guided by lateral rails during the dispensing and distribution of the chocolate and as far as the tapping-out mechanism, the data logger was integrated centrally into the underside of the mould in order to record the maximum acceleration values acting on the mould. This produced a wealth of sensor data, which could be used both for identification of the critical manufacturing parameters and also to create framework conditions for simulations. An analysis of the temperature and humidity values from the data logger showed that, for the moulds investigated, these do not represent critical influencing factors. Following an analysis of the cleaning agents used, it was also possible to rule out cleaning agents as a cause for the formation of stress cracks in the moulds under consideration. The focus thus turned to the influence of the mechanical stresses that occur as the critical parameter. Analysis of the acceleration values showed that high shock loads occur in the vibrating sections of the chocolate production process. It was noted that the highest mechanical stresses occurred in the vertical direction, indicated by a regular sign reversal.

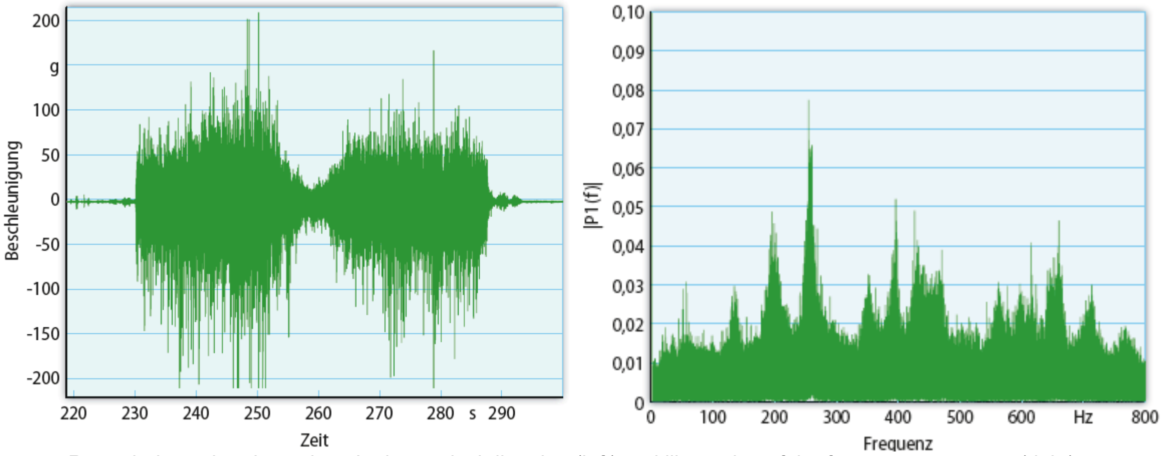

Figure 1. Recorded acceleration values In the vertical direction (left) and illustration of the frequency spectrum (right)

This can be traced back to the fact that the mould oscillates as a result of excitation. In addition to the amplitude, this is also indicated by the frequency. By way of example, the acceleration profile in the vertical direction with a scan frequency of 1600 Hz in the vibrating section of the manufacturing process is illustrated on the left in Figure 1. In order to determine the influence of the oscillation frequency, a Fourier transform can be applied to the acceleration values. This results directly in a frequency spectrum (on the right in Figure 1) that enables clear identification of the excitation frequencies. It was thus possible to demonstrate that there is not just one single frequency prevailing in the process, but rather a multitude of excitation frequencies, which overlap one another to create the oscillation. Nevertheless, it was possible to detect individual peaks in the frequency spectrum, i.e. there are specific frequencies at which the mould tends to oscillate more strongly. Focus was therefore drawn to both the oscillation amplitude and the excitation at critical oscillation frequencies as critical process parameters for further investigation.

Simulation

Carried out in parallel with the monitoring of process parameters, the purpose of the simulations was to deliver an improved understanding of the critical process parameters that promote the formation of cracks in the moulds. First of all, a modal analysis was performed to investigate whether the oscillation frequency matches the characteristic frequencies of the mould. The influence of the oscillation amplitude was then analysed in a transient structural simulation. The software Ansys (manufacturer: Ansys, Inc.) was used for both simulations. So that the chocolate moulds could be simulated as realistically as possible, all the relevant material parameters for the different polycarbonate types used were determined by conducting experiments. This comprised determining the modulus of elasticity and Poisson's ratio, as well as characterising the damping behaviour. Furthermore, the thermal capacity, thermal and thermometric conductivity and the coefficient of thermal expansion were also determined. It was thus possible to adapt the polycarbonate material model required for the simulation to the specific application in question. In addition, the environmental simulation parameters were taken directly from the recorded logger data. To be able to make as general a statement as possible about the characteristic frequencies, a simplified chocolate mould with five longitudinal and eleven cross ribs was constructed, with the ribs located at equidistant intervals. Here, the thickness of the ribs was deliberately varied between 1.5 mm, 2.5 mm and 3.5 mm. By determining the characteristic frequencies, it was possible to demonstrate that the rib thickness does not appear to have any great influence on the respective characteristic frequency position (Figure 2). Although a simplified mould without cavities was used for the observations at this stage, subsequent simulations demonstrated that this result also applies to real moulds with cavities. The influence of the characteristic frequency position on a possible failure of the mould will be discussed in more detail in the subsequent comparative consideration of the results. To investigate the influence of the oscillation amplitude, the behaviour of the moulds was analysed in the context of a transient structural simulation. Here, the deflection of the centre of the mould as compared with the undeformed state was calculated for various different accelerations. It was possible to demonstrate that, at an acceleration of just 15 m/s^2, there was already a vertical deflection of the centre of the mould measuring approx. 26.5 mm. With increasing rib thickness, this deflection reduced to 24 mm (t = 2.5 mm) and to approx. 23 mm (t = 3.5 mm), respectively. This corresponds with the expectation that the rigidity of the mould can be increased by using higher rib thicknesses. This result can also be transferred to real moulds with cavities, and is explained in more detail in the comparative consideration of the results.

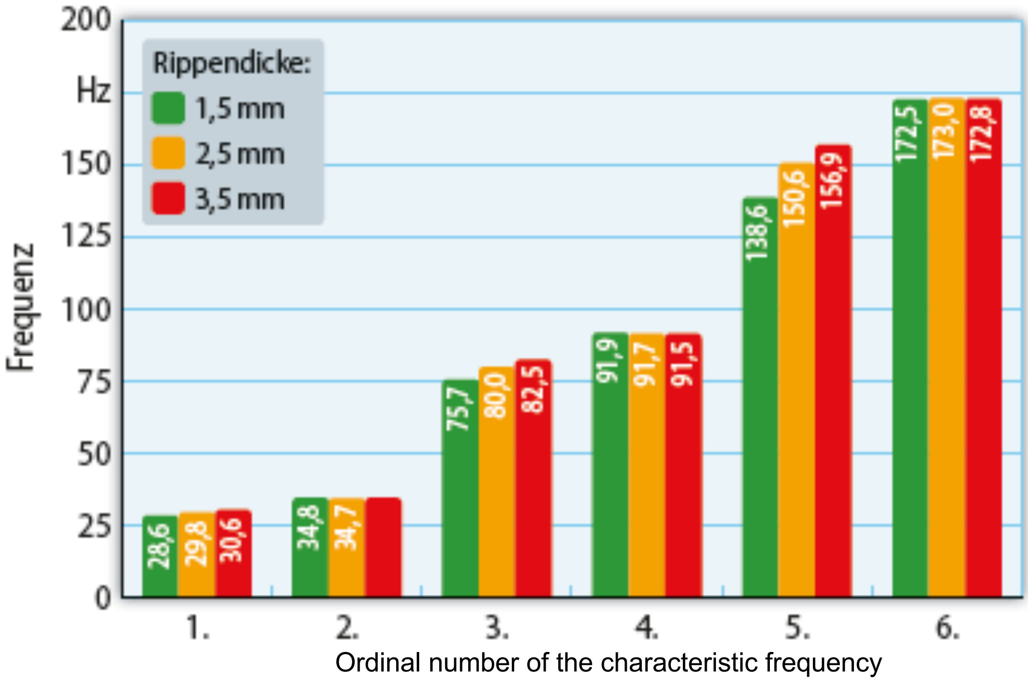

Figure 2. Illustration of the first six characteristic frequencies of a chocolate mould with various different rib thicknesses

Scanning electron microscopy

For the identification of the critical process parameters, a detailed analysis of the defects occurring is required in order to get a better understanding of how they arise. To do this, first of all individual defective chocolate moulds were analysed where it was established that there was a crack on the ribs starting from the reverse of the mould. The presence of mechanical weak points, e.g. weld lines, at the positions of the cracks had already been ruled out by carrying out injection moulding simulations. The crack edges were in each case prepared for investigation under a scanning electron microscope in order to obtain information about the failure mechanism. In Figure 3, both the crack initiation zone and the crack propagation direction can be seen. Crack propagation appears to progress cyclically, this being detected on the basis of the periodic advancement of the crack and the characteristic arrest lines. This progression was observed in all the moulds analysed, and will be interpreted in the following section, under consideration of the results, which will first of all be presented.

Consolidation of the results

To identify critical process parameters and thus determine the cause of the cracks occurring in some individual moulds, starting from the reverse of the mould, the final step involved bringing together the results from the data logger with the simulation results and the investigations of the crack pattern by means of scanning electron microscopy.

Monitoring of the process parameters revealed both high acceleration values and a greater oscillation of the mould at individual frequencies. However, following initial experimental optimisations of the mould, oscillation at an individual critical characteristic frequency could be ruled out. For this purpose, the rib thickness of a mould was increased by 1.2 mm. This resulted in a huge reduction in failure rates for the mould. However, since modifying the rib thickness on the basis of the modal analysis performed would not cause any significant change in the characteristic frequencies, failure resulting from excitation at a critical characteristic frequency was considered unlikely.

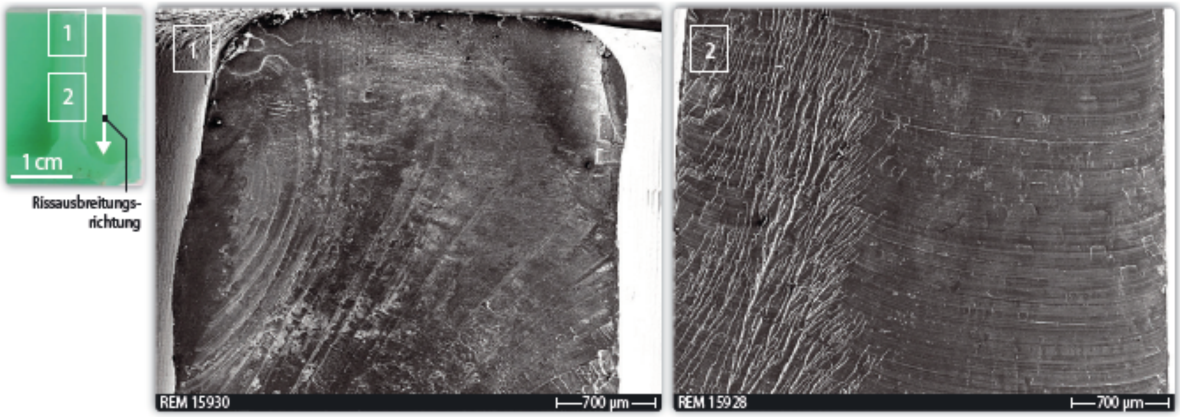

Figure 3. Fully opened-up crack (left) with crack propagation direction and SEM images of the marked positions. The crack initiation (1) and cyclical crack propagation can be identified on the basis of the arrest lines (2) Source: Crack propagation direction

The crack formation could therefore be traced back to increased oscillation amplitude. Because the cracking starts from the reverse of the mould, it was possible to draw conclusions in advance as to the critical loading case, illustrated in Figure 4. Accordingly, there are two possible points in the chocolate production process that can be assessed as critical. These are firstly a vibrating section for uniform distribution of the chocolate in the mould and, secondly, the final demoulding of the chocolate at the tapping-out mechanism, which involves a force being applied to the reverse of the mould for a brief period, together with flexing in the direction of the top of the mould (vertically upwards; see Figure 4). Here, the swinging motion elicited by the tapping-out mechanism could bring about a similarly critical loading case. As the signs of damage in the moulds investigated appeared after just a short period of time, conventional fatigue failure can be ruled out. The images from the scanning electron microscope make it clear that the crack propagation must be taking place in the vibrating section, as cyclical progression of the crack can be detected shortly after its initial formation. The crack pattern can be traced back to the associated opening and closing of the crack edges, leading to the creation of arrest lines. The issue is thus fatigue failure due to oscillation, which occurs after just a small number of cycles and is caused by overloading in the vibrating section. As the crack propagates further, the remaining load-bearing cross-section is reduced, which could ultimately bring about a sudden rupture. Initiation of the crack at the tapping-out mechanism can be ruled out; this would lead to a different crack pattern – initially there would be no cyclical progression, but there would instead be a larger area of damage.

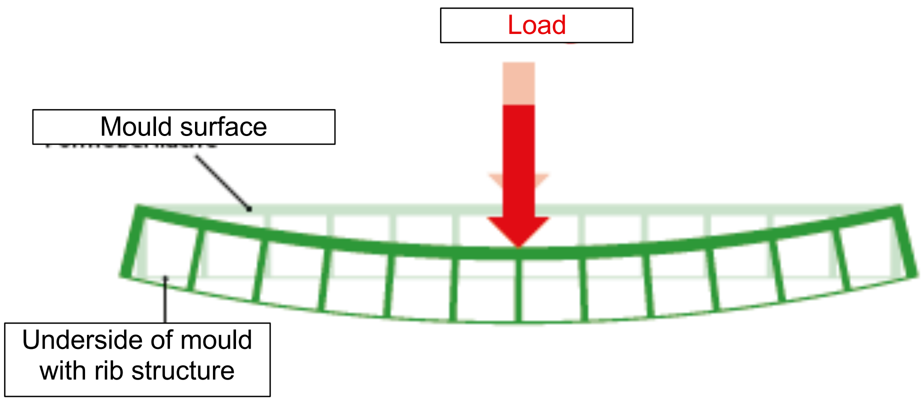

Figure 4. Schematic illustration of the loading case critical for crack formation

Summary

The approach developed is suitable for identifying critical paramenters in the chocolate production process. Here, there are no critical excitation frequencies; rather, the analysed cases of damage show high excitation amplitudes instead. It could be determined that the vibrating section was the critical point in the production process, both on the basis of the logger data and by means of scanning electron microscopy. One possible and comparatively simple solution can be implemented by simply increasing the thickness of the ribs. Reducing the excitation amplitude in the chocolate production process is another possible alternative. Initial results show that this would significantly reduce failure rates, thereby achieving greater reliability of the moulds. There is scope for further work with the integration of data loggers in moulds for various manufacturers in order to obtain statistically representative data and, as a result, to be able to determine the critical load thresholds for moulds with a range of different cavities. In the long term, this would make it possible for a mould fitted with sensors to be passed through the production process of various manufacturers, thereby allowing individually optimised moulds to be produced for each customer. W

Acknowledgements

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