Improvement of hot stamping production efficiency: research and application of shortening hot stamping holding time

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This study delves into the methodology and implementation of reducing the dwell time in hot stamping to enhance productivity. Through the optimization of dwell time, the primary objective is to boost productivity and reduce the production cycle duration, thereby introducing a more efficient and effective production approach to the hot stamping sector. It has been observed that the non-uniform cooling of the sheet material during hot stamping results in an uneven temperature distribution within the component, consequently impacting its mechanical properties. The pivotal solution to this issue lies in enhancing the contact between the hot blank and the die to enhance the uniformity of contact pressure. By utilizing mold materials with high thermal conductivity and elevating the contact pressure, the dwell time is effectively reduced, leading to enhanced production efficiency. Furthermore, a comparative analysis is conducted between the PCH technology and the in-die spring synchronization technology as solutions. The PCH technology facilitates high-quality one-die-multipart production, maintaining elevated throughput levels and stable part quality. On the other hand, the in-die spring technology enhances the consistency of contact pressure by eliminating die-blank contact asynchrony, thereby refining the hot stamping process. This research presents a viable solution to enhance the production efficiency of hot stamping, offering significant engineering application value.

Keywords: High-strength steel; Hot stamping; Contact thermal resistance; Uniform cooling; In-die spring.

1. Introduction

The study focuses on enhancing hot stamping productivity by reducing the holding time in hot stamping processes. Decreasing the holding time can potentially lead to increased productivity and quicker production cycle times. This strategy may involve adjusting production equipment or process parameters to optimize the hot stamping process, resulting in enhanced productivity through holding time reduction. The findings of this research could offer the hot stamping industry a practical approach to achieve more efficient and effective production, optimizing production costs while upholding quality standards.

In hot stamping, it is widely acknowledged that parts cool based on their shape, and cooling systems should be tailored accordingly [1]. While it is recognized that parts cool based on their shape, this method may not address the non-uniform temperature distribution within the part during cooling [2]. It is understood that thermal contact resistance (TCR) increases as pressure decreases. A decrease in TCR leads to an accelerated cooling rate [3]. The gap between the blank and the mold influences heat transfer; larger gaps impede heat transfer, whereas smaller gaps facilitate faster heat transfer.

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In practical hot stamping engineering, factors such as die structure and part geometry can result in asynchronous contact between the die and the hot blank. These asynchronous contact areas can exhibit variations in mechanical properties due to uneven cooling. The straightforward solution is often to extend the holding time, impacting the hot stamping rhythm and diminishing productivity.

2. How to improve the efficiency of hot stamping

The hot stamping process flow consists of the following steps: 1) Rapid downward movement of the slide; 2) Initiation of forming until mold closure; 3) Pressure holding and cooling phase; 4) Mold opening and swift upward movement of the slide. In a standard cycle: rapid downward travel time t1=2.00 seconds; forming and pressure holding time t2=5.5 seconds; mold opening and return time t3=1.3 seconds. When considering the blank's entry into the mold and the part's exit from the mold, the total cycle time t0=12.6 seconds, as depicted in Figure 1.

The closing and opening speeds of the thermoforming press, along with the automation speed, are nearing their maximum capacities. One of the challenges hindering further enhancement of the thermoforming cycle is the extended holding time. How can this holding time be further reduced?

Several measures can be implemented: 1) Utilization of high-conductivity mold steel; 2) Increased cooling water flow rate; 3) Lowering the cooling water temperature. However, the primary aspect in the heat transfer process for cooling is the contact between the hot blank and the mold. Optimal contact ensures high thermal conductivity, enabling the mold material's thermal conductivity to function efficiently. Conversely, contact thermal resistance remains the initial hurdle to overcome.

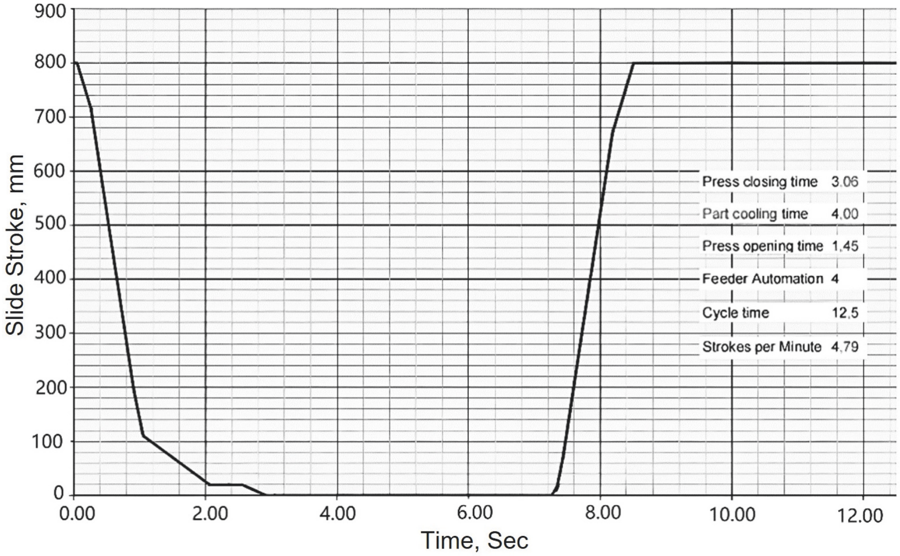

Fig. 1 Production beat for hot stamping of high strength steel

2.1. *Contact between hot blank and die*

The dissipation of heat from the sheet primarily depends on the contact heat transfer between the sheet and the die. The contact thermal resistance stands out as a crucial parameter influencing the cooling trajectory of the sheet, with its precision directly impacting the simulation accuracy of the hot stamping process. Resolving the contact thermal resistance presents a heat conduction inverse problem, influenced by various factors such as surface geometry, deformation characteristics at the contact point [4], material's physical parameters and mechanical properties, pressure on the contact surface, and the distribution of solid temperature gradients. This constitutes a complex multiscale heat-force coupling issue [5].

The contact between the hot sheet material and the mold during hot stamping, specifically the alteration in thermal conductivity due to varying positive pressure levels, represents the core challenge affecting the cooling effectiveness of hot stamped components, as illustrated in Figure 2. At a contact pressure of 40 MPa, the thermal conductivity is 3000 W/m²K. Contrastingly, at 5 MPa contact pressure, the thermal conductivity drops to 1500 W/m²K. The former showcases double the thermal conductivity compared to the latter.

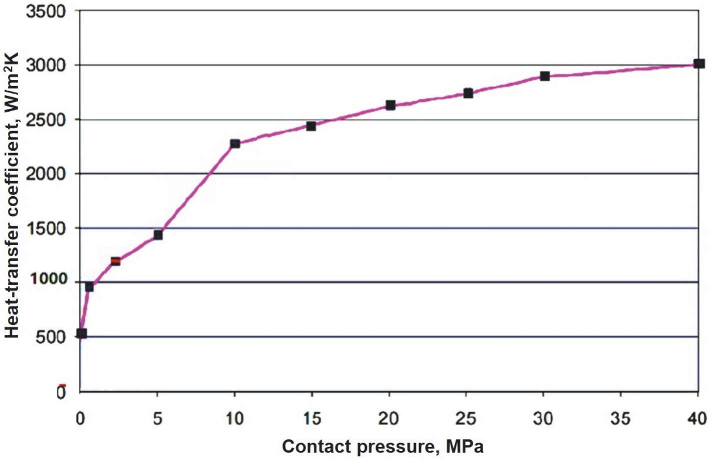

Fig. 2 Relationship between thermal conductivity and contact pressure

Therefore, it can be assumed that the mold material thermal conductivity, mold water flow and cooling water temperature are no longer the main bottleneck affecting the cooling of hot stamped parts. Reasonable increase in contact pressure is the main measure. How to increase the contact pressure is the key to solve the problem.

2.2. *Optimized cooling time for a single-cavity mold with multiple cavities*

In order to study this problem, the forming pressure, holding time and mold-out temperature field were measured with a one-cavity mold, a two-cavity mold and a multi-cavity mold, as shown in Fig. 3.

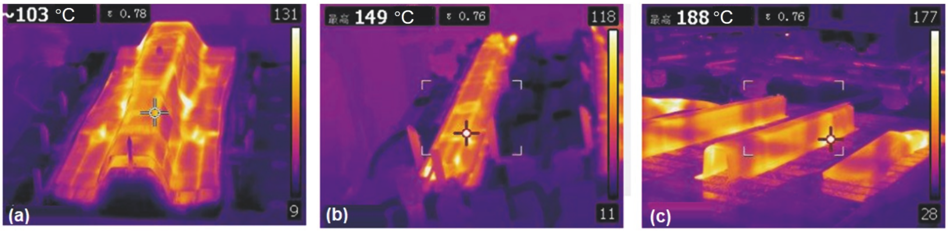

Fig. 3 Test results of mold-out temperature field for different mold configurations under the same process conditions: a) mold-out temperature field for a one-cavity mold; b) mold-out temperature field for a two-cavity mold; and c) mold-out temperature field for a multi-cavity mold.

In the case of a single-cavity mold with a plate thickness of 1.25 mm, the temperature field depicted in Figure 3(a) is observed after holding pressure cooling for 4.5 seconds under 600 tons pressure. Contrastingly, for a double-cavity mold with a plate thickness of 1.2 mm and subjected to 800 T pressure, the temperature field after holding pressure cooling for 5.5 seconds is illustrated in Figure 3(b). Moving to a multi-cavity mold with a plate thickness of 3.5 mm (comprising the patch plate and substrate), the temperature field resulting from holding pressure cooling for 18 seconds under 1200 tons pressure is shown in Figure 3(c).

For single-cavity molds with uniform material thickness, addressing the contact pressure issue can be resolved through mold research and matching processing. Similarly, for a two-cavity mold with distinct left and right parts and a single material thickness specification, ensuring contact pressure consistency can be achieved through meticulous mold grinding and matching procedures.

In the context of a multi-cavity mold accommodating varying plate thickness materials, the challenges lie in eliminating the thickness tolerance discrepancies among different materials and ensuring the uniformity of dimensional accuracy during mold processing. Additionally, practical considerations extend to maintaining consistent mold wear, all of which necessitate innovative mold technology solutions.

3. Technical solutions and strategies

3.1. *PCH technology and equipment*

Germany Schuler, for the difficulties of contact synchronization of a multi-cavity mold, proposed a PCH solution, as shown in Figure 4. Schuler's hot stamping press and press line concepts are combined with PCH flex technology to ensure superior quality, reliability [6]. A common method to increase machine productivity in hot stamping is the production of multiple parts in one die. In conventional hot stamping processes, this can lead to longer production beats, varying part tolerances, and increased or variable die wear due to the care of contact synchronization issues. The PCH technology, using a hydraulic pad and a modified mold, follows the use of Schuler's hot stamping presses. The end result is high-quality one-die, multi-piece production while maintaining the same high throughput levels and repeatable part quality. The case study has a blank thickness of 1.8 mm, and a comparison of beat times between the PCH and conventional processes is shown in Figure 5. In which the cooling time of the part is reduced from 12.5 seconds in the conventional method, to 6 seconds. The production beat in the case, from 23.6 seconds, is reduced to 11 seconds.

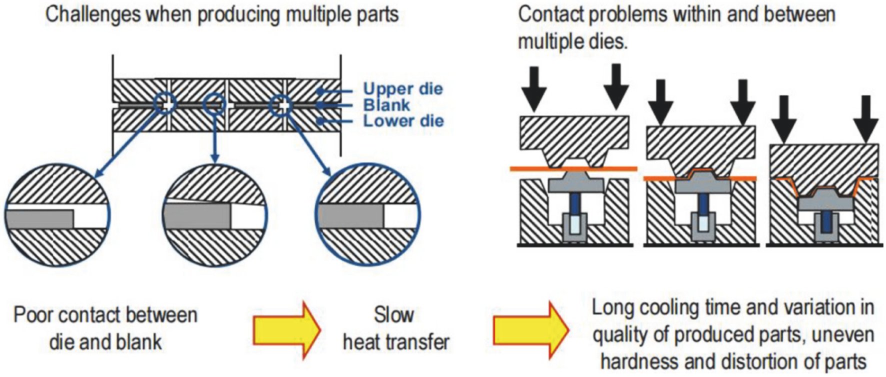

Figure 4 Contact problems and PCH solutions for multiple parts in one mold

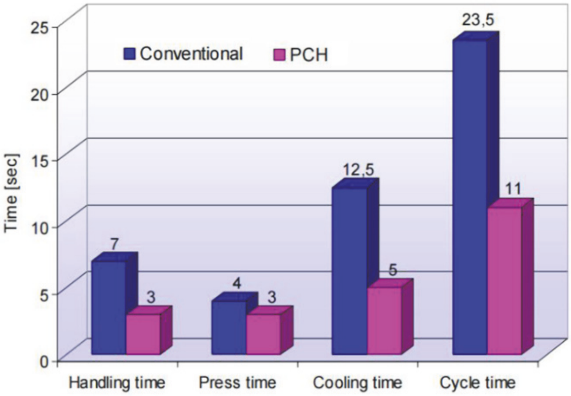

Fig. 5 The application of PCH technology improves the contact pressure consistency of the mold and shortens the production beat (Data from Shuler)

3.2. *In-mold spring synchronization technology*

Similar to the PCH technology is the in-mold spring technology. Inside the lower module of the mold, an elastic device is embedded for eliminating the difference in closing heights of different molds, thus synchronizing the contact between the mold and the blank and achieving contact pressure consistency. In-mold nitrogen springs, hydraulic cylinders, and gap elimination springs can be used to realize that different parts, or even different areas of the same part, can have consistent contact pressure [7]. In the case of a one-mold multipart mold, although the plate thickness error causes the contact pressure of each mold cavity to be out of sync, the pressure balance of different cavities can be achieved by touching down the independent hydraulic cylinders or mechanical springs, see Figure 6.

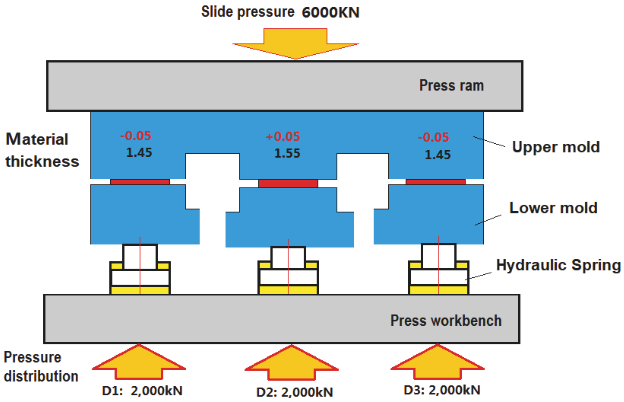

Fig. 6 Structural design of pressure equalization for one-mold-multipart molds

3.2.1. *Case of in-die springs for three parts in one mold*

The solution is shown in Fig. 7. The hot stamped part has a plate thickness of 2.8 mm and a forming holding pressure of 900 T. The stamping mechanical springs carry out a complementary height difference between the different molds after an actual cooling time of 10 seconds. Seven mechanical springs with a load of 28 tons each were used to compensate for the consistency of the contact pressure of the two cavities arranged symmetrically.

3.2.2. *Example of an in-die spring for a four-piece mold*

The solution is shown in Fig. 8. The hot stamped part has a plate thickness of 3.5 mm in the patch area and a forming holding pressure of 1050 tons. The stamped mechanical springs carry out the complementary height difference between the different molds with an actual cooling time of 12 seconds. In the center area of the mold, a mold with 2 symmetrically arranged cavities, the middle two cavities used 10 mechanical springs, each spring load 28 tons. For the two mold cavities symmetrically arranged on the outside, no springs were used, but the conventional method.

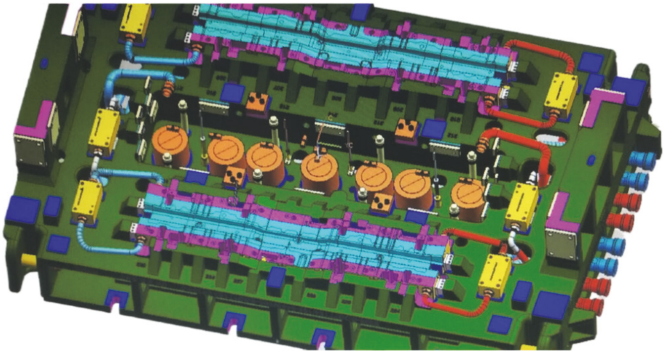

Fig. 7 Synchronization of the contact and consistency of the contact pressure of two parts in one mold using in-mold springs.

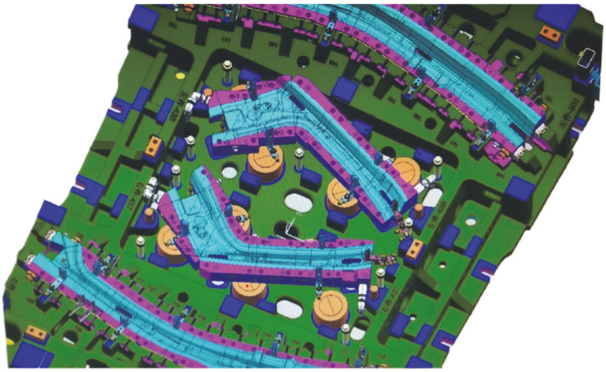

Fig. 8 Contact synchronization and consistency of contact pressure for 4 pieces in one mold with in-mold springs

4. Conclusion

Numerous influential factors contributing to the enhancement of the hot stamping production cycle have been thoroughly investigated. The primary focus has been on achieving consistent contact pressure, with a proposed solution involving the implementation of in-die mechanical springs.

Through the utilization of in-die spring technology, a tailored pressure distribution has been effectively realized, leading to a substantial reduction in cooling and holding times and offering a robust assurance for enhancing production efficiency.

Decreased the duration required for multi-cavity investigation and alignment, thereby abbreviating the mold delivery cycle and enhancing the comprehensive operational efficiency.

Enhance the mold's adaptability to diverse material batches, significantly mitigating the influence of material tolerances on part dimensions and functionality. Consequently, the on-line commissioning time of the mold can be reduced by approximately 1 to 2 weeks, ensuring the stability of the mass production process.

The in-mold spring flexibility device aligns with the mold installation, liberating it from equipment limitations and substantially enhancing its reliability.

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