Study on new hot stamping tool with low cost and high cooling efficiency

S Peng 1, J Zhou 1, S Qian 1, M Zhang 1, J Liu 1, Y Meng 1*

1 Chongqing University, Chongqing, China

* mengyi@cqu.edu.cn

Abstract. A new manufacturing method of hot stamping tool with CCC is proposed in this study. A pair of optimal hot stamping tool should have long service life, low manufacturing cost and good cooling performance simultaneously. The CuCrZr alloy and Fe-based alloy is selected as interlayer layer (IL) and surface layer (SL) respectively. The maximum stress of new tool was less than the yield strength of the corresponding welding materials, which demonstrated that new tool manufactured by surfaced technology could satisfy the strength requirement and deserve further research.

1. Introduction

Hot stamping technology for ultra-high strength steel is widely used in automotive industry [1-4]. The cooling channel of traditional hot stamping tool is usually linear, and the distance between cooling channel and tool surface is not uniform for complex hot stamping tool surface [5]. It is difficult to meet the requirement of efficient and uniform cooling. If the hot stamping tool is made of homogeneous material, the tool performance of these position below the cooling water channel is too high, which will result in the waste of expensive materials and increase the manufacturing cost [6-9]. Moreover, the hot stamping die made of the homogeneous material would be difficult to manufacture the conformal cooling channels (CCC).

Therefore, a new tool structure for hot stamping die with CCC is proposed in this paper, as shown in Figure 1. The cooling efficiency of the tool is improved by using high thermal conductivity material and conformal cooling channel structure. Firstly, the matrix with lower half of CCC shape is machined, hardened and tempered 45 steel is chosen as matrix layer and then the pre-bended copper pipes are embedded into the cooling channels of matrix; then again, the welding materials with high thermal conductivity are welded on the surface of matrix and copper pipes to form intermediate layer. Finally, the heat-resisting welding materials are welded on surface of intermediate layer to obtain surface layer. Compared with the traditional hot stamping tool, this method realizes the allocation according to require of material properties. Namely, surface layer bears severe high-temperature conditions, the intermediate layer improves cooling efficiency for hot stamping tool, and the matrix meets the basic working requirements.
2. Materials and methods

In this study, the material of blank was 22MnB5 with a thickness of 1.7mm. Hot tensile tests were carried out under the temperature range of 500, 600, 700, 800, 900°C and strain rates of 0.01, 0.1, 1s\(^{-1}\) on WDW-100 universal testing machine. The tensile sample is shown in Figure 2. Moreover, quenched and tempered 45 steel was chosen as the substrate material. Fe-based and Co-based alloy were preselected as the surface layer, CuCrZr and CuBe alloy were preselected as the intermediate layer.

The matrix specimens were firstly cleaned and preheated to 400°C and then the surfacing process was carried out by using HRWS-3250 type welding machine according to test design requirement, finally every specimen was tempered at 500°C after welding. The finished surfacing specimens are shown in Figure 3.
3. Results and discussion

3.1. Mechanical properties of blank

The true stress-strain curves at different strain rate and temperature are shown in Figure 4, which is necessary for the establishment of material models in ABAQUS software. At the strain rates of 0.01, 0.1 and 1s\(^{-1}\), the stress decreases with the increasing temperature, and the fracture strain firstly increased and then decreased slightly with the increasing temperature, and the maximum fracture strain was obtained at 700℃. Therefore, the temperature at 700℃ is more favorable for forming, which has good plasticity and smaller forming resistance. According to actual production process, the temperature range of blank during forming is about 650~750℃, which guaranteed the best high-temperature plasticity.

3.2. Mechanical properties of surfacing materials

The true stress-strain curves of Fe-based alloy, Co-based alloy, CuCrZr alloy and CuBe alloy at different temperatures are shown in Figure 5. The compressive yield strength of Co-based alloy at 25, 150, 250, 350, 450 and 550℃ is 588, 344, 338, 318, 310 and 292MPa, respectively. The compressive
yield strength of the Fe-based alloy at 25, 150, 250, 350, 450 and 550℃ is 1608, 1480, 1450, 1394, 1328 and 1198MPa respectively. It is obvious that the yield strength of Fe-based alloy is much higher and more stable than Co-based alloy. Therefore, it is better to choose Fe-based alloy as the surface layer material from the analysis of material mechanical properties. Also, the yield strength of CuCrZr alloy at 25, 150, 250 and 350℃ is 135, 121, 120 and 96MPa respectively. The yield strength of CuBe alloy at 25, 150, 250 and 350℃ is 187, 147, 138 and 156MPa respectively.

Figure 6 shows the true stress-strain curves of interface between two surfacing materials. The compressive yield strength of all interfaces at different temperature is listed in Table 1. The yield strength of Fe-based + CuCrZr is better than that of Co-based + CuCrZr. Although the yield strength of CuCrZr is slightly lower than that of CuBe, the yield strength of 45 steel + CuCrZr is greater than that of 45 steel + CuBe.

![Figure 5. The true stress-strain curves of single surfacing materials.](image-url)
**Figure 6.** The true stress-strain curves of two surfacing materials.

| Temperature/°C | 25 | 75 | 150 | 250 | 350 |
|---------------|----|----|-----|-----|-----|
| Yield strength of 1#/MPa | 379 | -- | 343 | 379 | 376 |
| Yield strength of 2#/MPa | 186 | -- | 171 | 182 | 170 |
| Yield strength of 3#/MPa | 430 | -- | 312 | 301 | 255 |
| Yield strength of 4#/MPa | 211 | -- | 186 | 175 | 205 |
| Yield strength of 5#/MPa | 383 | 368 | 361 | -- | -- |
| Yield strength of 6#/MPa | 192 | 236 | 208 | -- | -- |

### 3.3. Heat conductivity and thermal expansion coefficient of surfacing materials

The heat conductivity and thermal expansion coefficient of Fe-based and CuCrZr is displayed in Table 2 and Table 3. These thermal parameters which directly influence the stress and temperature contribution will be input into ABAQUS software for process simulation. The thermal conductivity of Fe-based alloy and CuCrZr are greater than Co-based alloy and CuCrZr respectively, and then the thermal expansion coefficients of Fe-based and CuCrZr were smaller than Co-based and CuBe respectively. At last, CuCrZr and Fe-based alloy was selected as the intermediate layer material and surface layer material respectively.
Table 2. Thermal expansion coefficient of two alloy materials (unit in $10^{-5}$/°C).

| Temperature/°C | 50   | 150  | 250  | 350  | 450  |
|----------------|------|------|------|------|------|
| Fe-Based       | 1.50 | 1.36 | 1.36 | 1.34 | 1.32 |
| CuCrZr         | 1.63 | 1.67 | 1.77 | 1.76 | 1.74 |

Table 3. Heat conductivity of two alloy materials (unit in W/m•°C).

| Temperature/°C | 25   | 100  | 200  | 300  | 400  |
|----------------|------|------|------|------|------|
| Fe-Based       | 39   | 43   | 48   | 51   | 54   |
| CuCrZr         | 166  | 154  | 145  | 138  | 134  |

3.4. Stress filed comparison of traditional and new tool

Figure 7 shows the stress field distribution of traditional and new tool at the end of stamping. The simulation result indicated that new tool will be subjected to lower stress than traditional tool, which attributed to high heat conductivity and low elastic modulus of intermediate layer. The yield strength of welding materials under corresponding temperature are listed in Table 4. As seen in Table 4, each value of maximum stress was less than yield strength under corresponding temperature, which demonstrated that new tool manufactured by surfacing technology can satisfy the strength requirement of hot stamping process.

![Stress field comparison of traditional and new tool](image)

Table 4. The highest temperature, the maximum stress and yield strength.

|                        | SL   | IL  | substrate |
|------------------------|------|-----|-----------|
| Highest temperature /°C| 117  | 78  | 54        |
| Maximum stress /MPa    | 254  | 100 | 75        |
| Yield strength /MPa     | 1480 | 121 | 480       |

4. Conclusions

(1) A new manufacturing method of hot stamping tool with CCC is proposed in this study. The CuCrZr alloy and Fe-based alloy is selected as interlayer material and the surface layer material respectively.
(2) The maximum stress of new tool was less than the yield strength of the corresponding welding materials, which demonstrated that new tool manufactured by surfacing technology could satisfy the strength requirement and deserve further research.

References
[1] H Karbasian and A E Tekkaya 2010 J. Mater. Proc. Technol 210 2103–18
[2] H Bok, M Lee, E J Pavlina, F Barlat and H Kim 2011 Int. J. Mech. Sci 53 744–752
[3] M Li, T Chiang, J Tseng and C Tsai 2014 ProcediaEng 81 1786–91
[4] T Maeno, K Mori and M Fujimoto 2015 CIRP Ann. Manuf. Technol 64 281–284
[5] M Merklein and J Lechler 2006 J. Mater. Proc. Technol. 2006 452–455
[6] B He, L Ying, P Hu, Y Yu, X Zhao and LW Zhang 2014 Adv. Mater.Res. 1063 186–189
[7] He B, Ying L, Li X D and Hu P 2016 Appl. Therm. Eng 106 1176–89
[8] Chen J S, Gong P H, Liu Y S, Zheng X Y and Ren F 2017 Int. J. Adv. Manuf. Technol 93 1357–65
[9] W Lim, H Choi, S Ahn and B Kim 2014 Int. J. Adv. Manuf. Technol 70 1189–1203