Mechanical performance testing of hot-stamped tailored-tempering-properties U-shaped parts

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This experiment devised a set of cold-hot partitioning molds for preparing U-shaped components made of 22MnB5 with variable strength. Employing a hot stamping process, the molds were set at temperatures of 400°C, 450°C, and 500°C respectively. Samples were taken from the soft and hard regions of the fabricated components, and the transition zone length was determined through hardness testing. The mechanical properties of the hard and soft regions were assessed via uniaxial tensile tests, yielding the corresponding engineering stress-strain curves, tensile strength, and elongation at fracture. Microstructural observations were conducted using SEM to summarize the influence of mold temperatures on the mechanical properties of the produced components.

Keywords: Hot Stamping; 22MnB5; Tailored-Tempering-Properties; U-shaped parts.

1. Introduction

In the contemporary industrial milieu, imperatives such as lightweight, energy efficiency, environmental sustainability, heightened efficacy, and elevated safety standards have emerged as paramount considerations across various sectors. These imperatives necessitate the development of structural components with elevated strength and superior malleability while simultaneously endeavoring to minimize mass during the production process. High-strength steel [1], known for its commendable tensile strength and favorable ductility, emerges as a promising material for augmenting the load-bearing capacity and safety margins of components. Its applications span diverse fields including automotive manufacturing, aerospace engineering, and architectural construction.

Traditional cold-forming methodologies are often associated with significant forming loads, challenges in controlling spring back, and the propensity for parts to develop cracks and exhibit poor dimensional stability. In response to these challenges, the integration of heat treatment with forming processes has gained considerable attention [2]. This approach involves subjecting the sheet material to Austenitization temperatures before shaping and subsequently quenching it to achieve a martensitic microstructure, thereby yielding components with ultra-high strength (1500~1700 MPa). Throughout the hot-forming process, the material exhibits excellent plasticity and resilience, thereby mitigating forming complexities, residual stresses, and the effects of spring back. Consequently, this enhances the precision of shaping, material properties, and overall stability.

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To address the diverse mechanical property requirements across different regions of components and thereby enhance safety performance during manufacturing, the concept of variable-strength hot-formed components from high-strength steel has emerged [3]. This research aims to develop a set of hot stamping cold-hot partitioning molds tailored for fabricating Tailored-Tempering-Properties U-shaped components from 22MnB5. By meticulously configuring distinct mold temperatures to achieve varying cooling rates, the resulting U-shaped components exhibit nuanced performance attributes across different regions.

The investigation subjected the specimens to hot stamping at temperatures of 400°C, 450°C, and 500°C, respectively. Samples were extracted from the side and bottom flanges of the U-shaped parts. Hardness testing was conducted to calculate the transition zone length of the components. Additionally, uniaxial tensile tests were performed to obtain engineering stress-strain curves, tensile strength, and elongation. SEM analysis was employed to analyze the microstructural morphology and phase composition of the lower soft regions of the components. This analysis aimed to summarize the influence patterns of mold temperature and cooling rate on the microstructure and mechanical properties of hot-formed components.

2. Experimental methods

2.1. *Experimental materials*

The steel used in this experiment is the uncoated Xinyu Iron and Steel CR1000/1500HS plate, also known as 22MnB5, which consists of a ferrite and pearlite microstructure. The dimensions of the plate are: length 820 mm × width 426 mm × thickness 1.6 mm. Its chemical composition of elements is shown in Table 1, and the engineering stress-strain curve is illustrated in Fig. 1. The yield strength and ultimate tensile strength are 360 MPa and 530 MPa, respectively.

Table 1. Chemical composition of 22MnB5 (wt. %).

C	Si	Mn	P	S	Cr	Ti	B
0.209	0.249	1.342	0.009	0.006	0.204	0.031	0.002

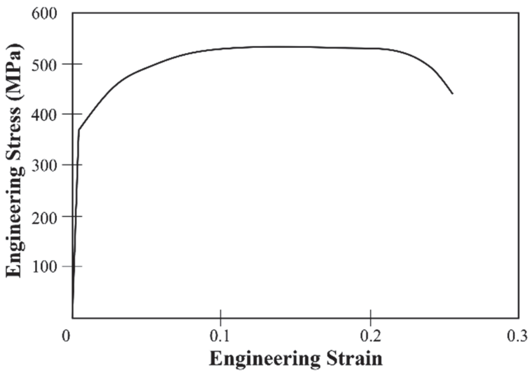

Fig. 1. The engineering stress-strain curve of 22MnB5 [4].

2.2. *Experimental equipment*

The experiment independently designed and developed a set of cold-hot partitioning Tailored-Tempering-Properties U-shaped hot forming molds, as shown in Fig. 2(a). Due to different temperatures during the quenching process, the mold was divided into a cold mold and two hot molds, as depicted in Fig. 2(b). The central part represents the cold mold, maintained at room temperature. Its rapid cooling rate results in higher strength in this portion of the component, thus termed the hard zone. On the other hand, the flanking sections represent the hot molds, maintained at temperatures of 400°C, 450°C, and 500°C. With a slower cooling rate, these areas exhibit lower strength, hence referred to as the soft zone of the formed component. The formation of the U-shaped component is depicted in Fig. 3, with annotations detailing the distribution of the four distinct regions: the bottom and sides of the hard zone, and the bottom and sides of the soft zone.

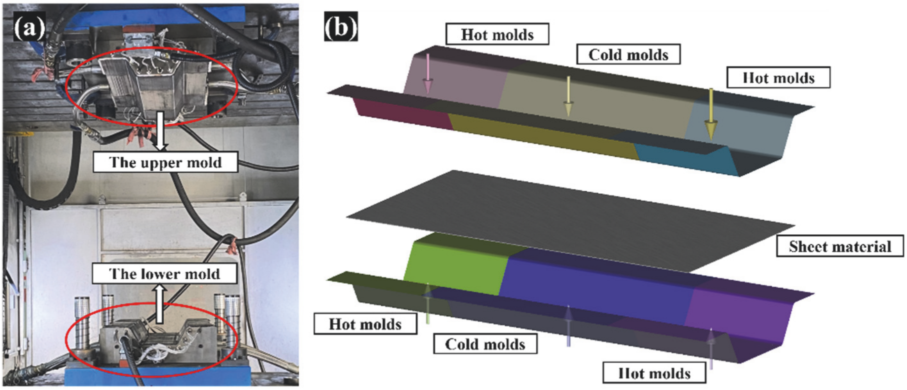

Fig. 2. Experimental equipment: (a) Upper and lower molds (b) Cold and hot mold partitioning.

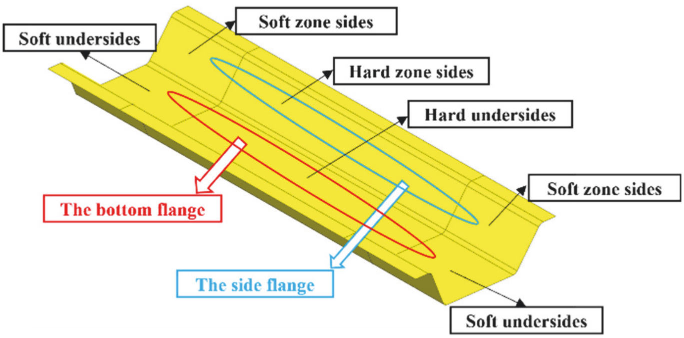

Fig. 3. Distribution of U-shaped parts formed by hot stamping.

2.3. *Hot stamping process*

The hot stamping forming process is shown in Fig. 4. The sheet metal is heated to 930℃ and kept warm for 330 seconds. After complete austenitization, it is transferred from the roller bottom furnace to the mold cavity within 10 seconds. A 300t press is used to maintain pressure for 15 seconds before quenching and forming, and then removed from the mold cavity.

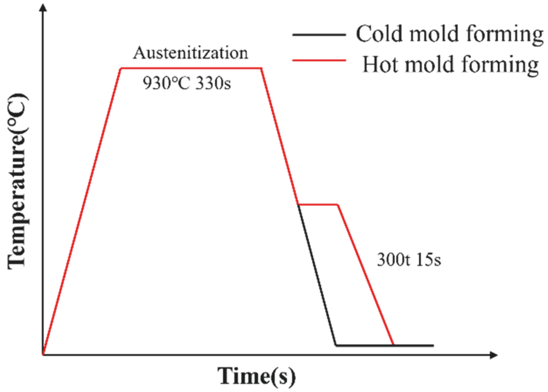

Fig. 4. Schematic diagram of the hot stamping process.

3. Performance test

3.1. *Hardness test*

The bottom of the U-shaped part was sampled, and the hardness was measured every 4mm tested by Vickers hardness tester (430SVD). The length of the transition zone of the formed part formed at different mold temperatures was calculated through the change of hardness value. The hardness measurement results are shown in Fig. 5, (a) is the hardness test result of the left transition zone of the part, and (b) is the hardness test result of the right transition zone of the part. As can be seen from the trend of the line chart, the left transition area of the formed part is 45mm, and the right transition area is 70mm, which meets the design requirements.

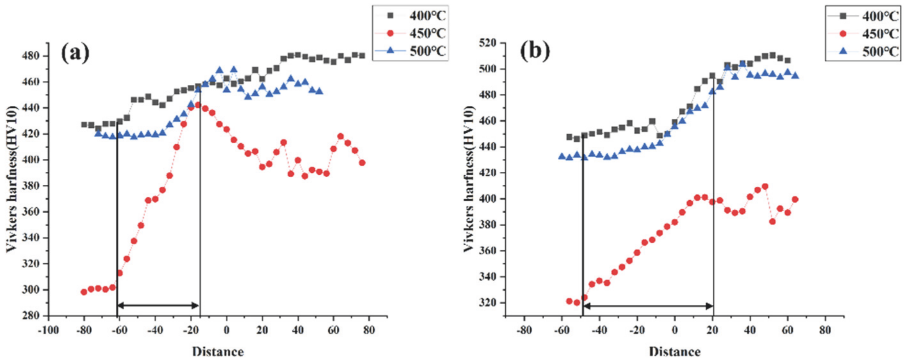

Fig. 5. Hardness test results (a) left transition zone of the part (b) right transition zone of the part.

3.2. *Uniaxial tensile test*

Samples were taken from the bottom and side surfaces of the hard and soft areas of the U-shaped parts formed by stamping at the above three hot mold temperatures. Quasi-static uniaxial tensile tests were conducted according to the GB/T228 standard, and the sample size is shown in Fig. 6. The Shimadzu tensile testing machine (AG-IC) was used for stretching, with a stretching speed of 4.5 mm /min.

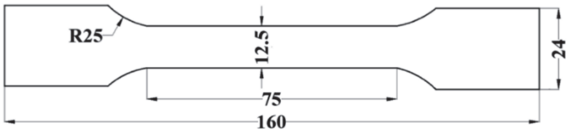

Fig. 6. Schematic diagram of uniaxial tensile specimen.

Table 2 presents a comprehensive overview of the tensile strength and elongation at break of materials across different sections of U-shaped parts subjected to stamping under three distinct hot die temperatures. Engineering stress-strain curves for various sections of U-shaped parts formed via hot stamping at temperatures of 400°C, 450°C, and 500°C are depicted in Fig.s 7 (a) - (c). Fig. 7 (d) provides a comparative analysis of the tensile strength and elongation across different regions of the U-shaped part, with the line graph illustrating tensile strength and the bar graph depicting elongation.

The higher tensile strength observed in the hard zone compared to the soft zone can be attributed to several factors. The lower mold temperature and faster cooling rate in the hard zone facilitate greater transformation of austenite into martensite during the quenching process. Additionally, the side area of the U-shaped part exhibits higher tensile strength than the bottom due to tighter adherence of the mold to the plate during stamping, leading to increased pressure on the plate and subsequent transformation of more austenite into martensite.

In the hard area of U-shaped parts, where the cold mold temperature remains at room temperature, the performance of this area is minimally affected by the hot mold temperature. Tensile strength on the side of the hard zone at the three different hot mold temperatures exceeds 1500 MPa, significantly surpassing other areas. However, slight variations in tensile strength are observed on the bottom surface of the hard zone under three different hot mold temperatures, ranging from 1000-1200 MPa. This discrepancy is likely attributable to errors resulting from heat transfer between the cold and hot molds during the stamping process.

For the soft area of U-shaped parts, hot mold temperatures are set at 400°C, 450°C, and 500°C. Tensile strength on the side of the soft area ranges from approximately 800 MPa to 900 MPa, while on the bottom of the soft area it ranges from about 750 MPa to 850 MPa. Fig. 7 (d) illustrates that as the hot mold temperature increases, tensile strength decreases while elongation increases. This phenomenon arises from the decreasing cooling rate during sheet metal stamping as the hot die temperature rises, leading to reduced transformation of austenite into martensite and subsequently lower strength.

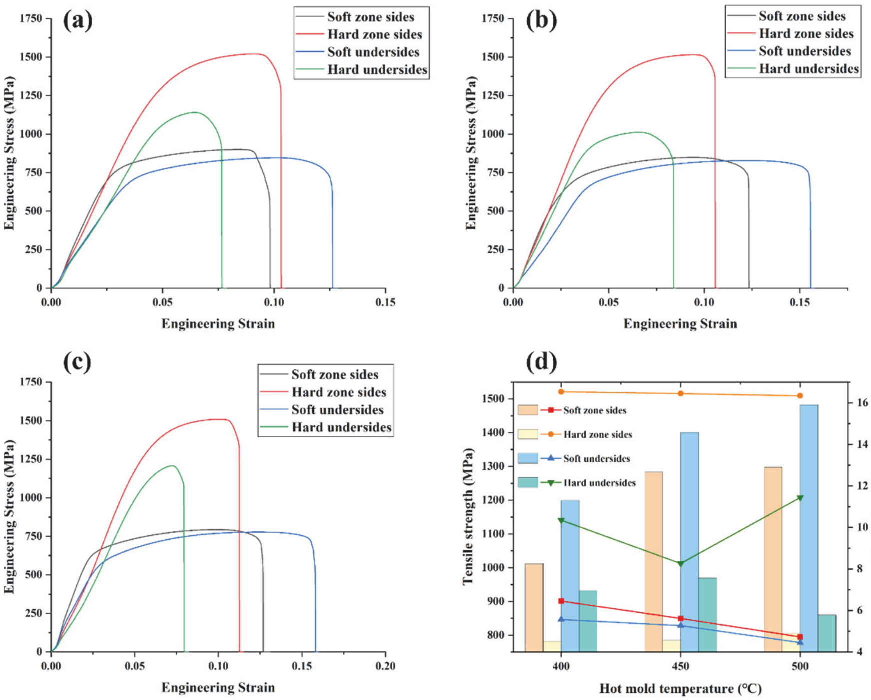

Fig. 7. (a-c) Engineering stress-strain curves of 400°C, 450°C, and 500°C (d) Comparative graph of tensile strength and elongation results for different regions of the U-shaped part.

Table 2. The results of uniaxial tensile tests.

Temperature	Part location	Soft zone		Hard zone	
		Tensile strength (MPa)	Elongation (%)	Tensile strength (MPa)	Elongation (%)
400°C	The bottom flange	846.563	11.3	1141.094	6.94
	The side flanges	901.094	8.26	1521.250	4.52
450°C	The bottom flange	828.438	14.58	1012.344	7.96
	The side flanges	849.532	12.66	1516.094	4.56
500°C	The bottom flange	778.125	15.9	1207.969	5.78
	The side flanges	794.688	12.9	1509.375	4.90

3.3. *SEM microstructure observation*

To further investigate the effect of mold temperature on the performance of formed parts, we combined scanning electron microscopy to analyze the microstructure and composition of the parts. Sample the bottom of the soft area of the U-shaped part and observe its microstructure through scanning electron microscopy. The results are shown in Fig. 8. It can be seen that the bottom of the soft zone of the part is a mixed structure of martensite, bainite, and residual austenite. With the increase of hot mold temperature, the Flat noodles martensite decreases and the tempering microstructure increases. Based on the results of the tensile test, the increase in hot mold temperature is accompanied by a decrease in tensile strength and an increase in elongation, which is consistent with the observation results of the microstructure.

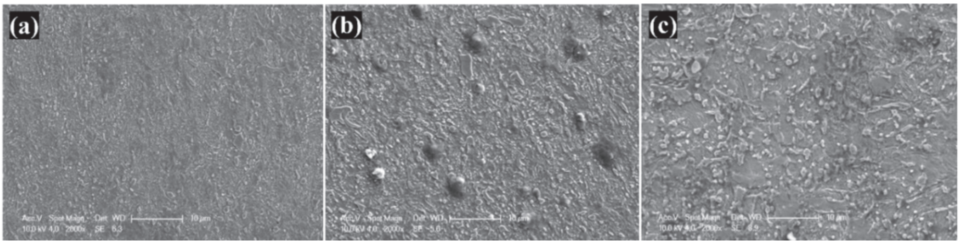

Fig. 8. SEM observations at the bottom of the soft zone of the U-shaped parts (a) 400°C (b) 450°C (c) 500°C.

4. Conclusions

The cold and hot partition mold device developed in this experimental design can realize the forming and manufacturing of variable strength parts, and the U-shaped parts produced have two transition zones, with lengths of 45 mm and 70 mm respectively.

Set the hot mold temperature to 400°C, 450°C and 500°C respectively, and test the mechanical properties of different areas of the formed parts, the tensile strength of the side of the hard area has reached 1500 MPa, the bottom of the hard area is 1000~1200 Mpa, the side of the soft area is 800~900 MPa, and the bottom surface of the soft area is 750~850 MPa.

Combined with the microstructure composition to explore the influence of mold temperature on mechanical properties, with the continuous increase of mold temperature, the martensitic content decreases, the tensile strength decreases accordingly, and the elongation increases accordingly.

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