马鞍山钢铁股份有限公司
MAANSHAN IRON & STEEL COMPANY LIMITED

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Investigation of Hot Stamping Process of 22MnB5 Based on Metallo-Thermo-Mechanical Theory

Liu Yonggang, etc.

Auto Sheet Strategic Business Unit, Maanshan Iron & Steel Co., Ltd., Maanshan, China

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Content

1 Introduction

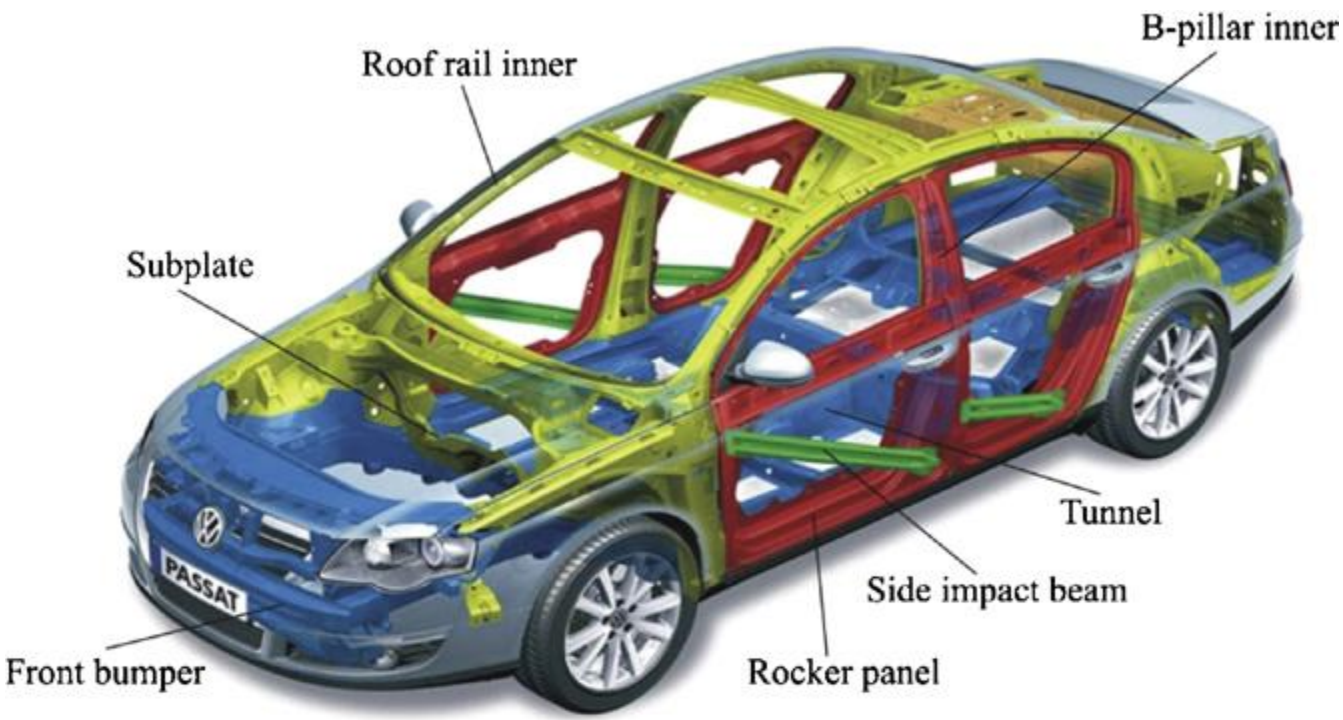


Fig.1 Hot stamped parts in a typical middle class car*

* Karbasian H, *et al*. *Journal of Materials Processing Technology*, 2010,210:2103-2118.

1 Introduction

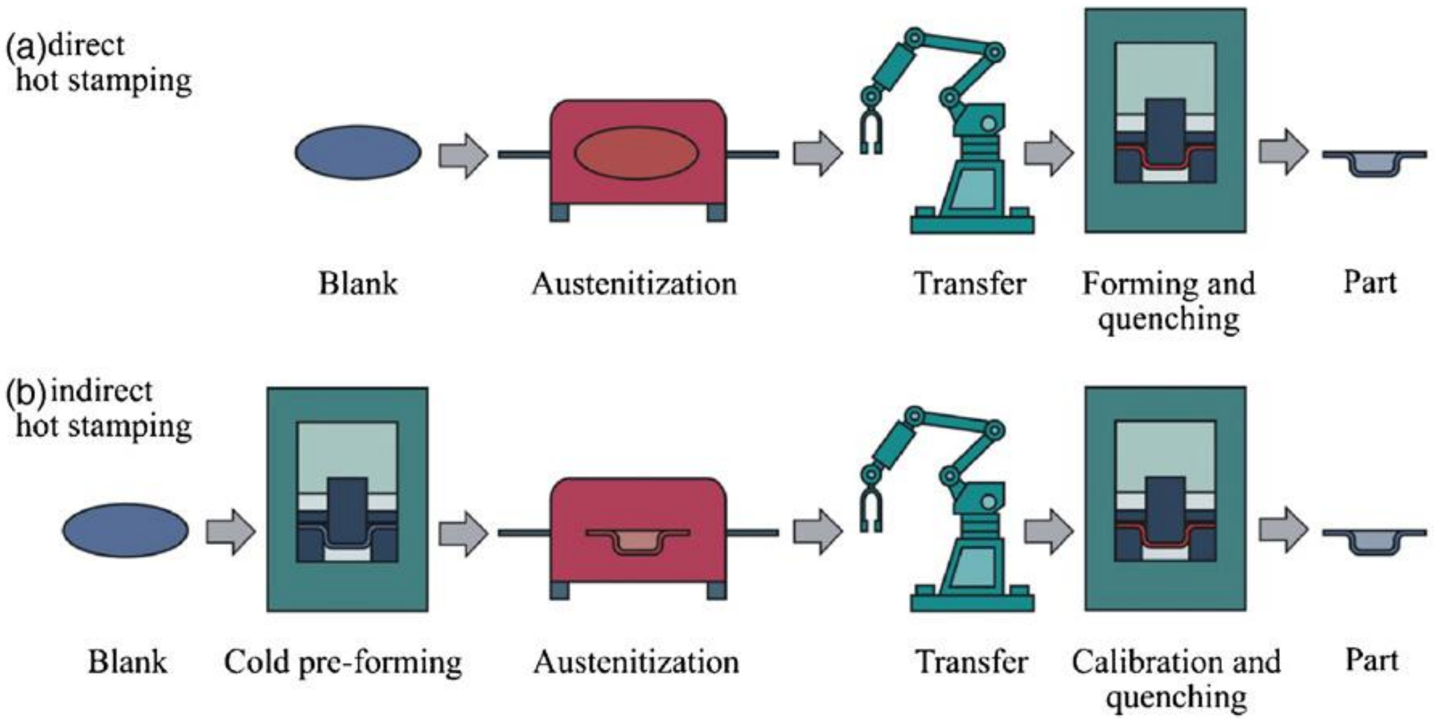


Fig.2 Basic hot stamping process chains: (a) direct hot stamping, (b) indirect hot stamping.*

* Karbasian H, *et al*. *Journal of Materials Processing Technology*, 2010,210:2103-2118.

1 Introduction

Hot stamping processing

- First, the high-strength steel sheet is heated in the furnace to **achieve full-austenitic transformation**.
- Subsequently experience the **forming process**
- Finally, **quenching** in forming die equipped with a cooling system to ensure that cooling rate is greater than the critical value of **27℃/S**.

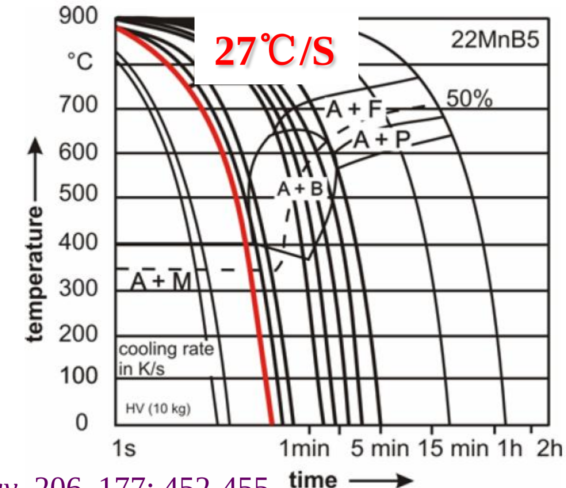


Fig.3 The CCT diagram of 22MnB5.*

* Merklein M, *et al*. *Journal of Materials Processing Technology*, 206, 177: 452-455.

1 Introduction

- Recently, a great many of previous researches only have taken the phase transformation and the mechanical properties into account for hot stamping analyses, but ignoring the effect of cooling water *.
- In this paper, considering the cooling system, hot stamping process of a 22MnB5 box component is simulated based on the metallo-thermo-mechanical theory to discuss the temperature and microstructure evolution rule, and analyze the influences of holding time on the mechanical properties and final microstructure distribution of component.

* Cui J, *et al*. *Journal of Materials Engineering and Performance*, 2012, 21: 2244–2254.

* Xing Z W, *et al*. *Materials Science and Engineering A*, 2009, 499: 28-31.

2 Methodology

- **Hot stamping process is a complex multi-field problem involving the reciprocal coupling among the thermal, metallurgical and mechanical fields.**

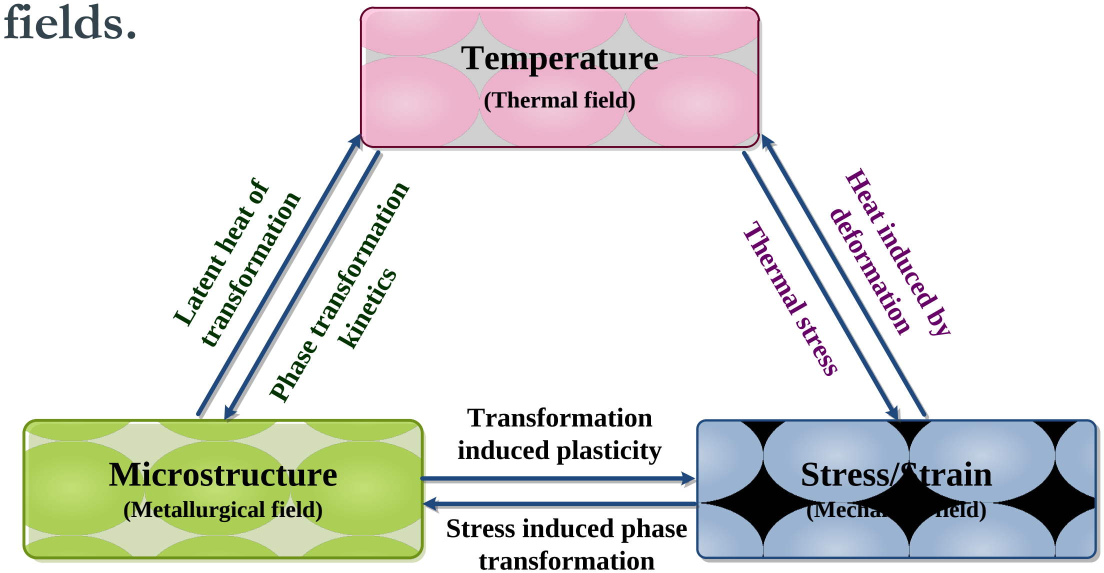


Fig.4 Illustration of the metallo-thermo-mechanical coupling relationship in hot stamping process.*

* Caner Simsir, *et al. Computational Materials Science*, 2008, 44: 588-600.

* T Inoue, K Arimoto. *Journal of Materials Engineering and Performance*, 1997, 6: 51-60.

2 Methodology

Temperature model

- Fourier's law *

$$\rho c\frac{\partial T}{\partial t}=\frac{\partial}{\partial x}(\lambda\frac{\partial T}{\partial x})+\frac{\partial}{\partial y}(\lambda\frac{\partial T}{\partial y})+\frac{\partial}{\partial z}(\lambda\frac{\partial T}{\partial z})+Q$$

- Initial condition

$$T\,|_{t=0}=T_0(x,y,z)$$

- Boundary condition

$$-\lambda\frac{\partial T}{\partial n}\bigg|_{\Gamma}=\boldsymbol{H}_{\mathrm{C}}(T_{\mathrm{B}}-T_{\mathrm{E}})+\boldsymbol{H}_{\mathrm{R}}(T_{\mathrm{B}}^4-T_{\mathrm{E}}^4)$$

- $\boldsymbol{H}_{c}$ and $\boldsymbol{H}_{R}$ are the convection and radiation heat transfer coefficients

* Caner Simsir, *et al. Computational Materials Science*, 2008, 44: 588-600.

2 Methodology

Phase transformation model

- Diffusional controlled transformations*

For ***Ferrite***, ***Pearlite*** and ***Bainite*** transformation

$$\xi = 1 - \exp(-\boldsymbol{b}\boldsymbol{t}^{n})$$

$$\boldsymbol{n} = \frac{\ln\left[\ln(1-\xi_1)/\ln(1-\xi_2)\right]}{\ln(t_1/t_2)}$$

$$\boldsymbol{b} = -\frac{\ln(1-\xi_1)}{t_1^n}$$

- ***b*** and ***n*** are constants, which can be confirmed by isothermal transformation (TTT) diagram.

* Caner Simsir, *et al. Computational Materials Science*, 2008, 44: 588-600.

2 Methodology

Phase transformation model

- Non-diffusional controlled transformations*

For *martensite* transformation

$$\xi = 1 - \exp[-\alpha(M_s - T)$$

- M_s is martensitic point.
- α is constant.

* Koistien D F, *et al. Acta Metallurgica*, 1959, 7: 50-60.

2 Methodology

Stress/strain model

- Fourier's law $$\bar{\sigma} = K(\bar{\varepsilon}_0 + \bar{\varepsilon})^n \dot{\bar{\varepsilon}}^m e^{(\beta/T)}$$

- Strain increment * $$\dot{\varepsilon}_{ij} = \dot{\varepsilon}_{ij}^{e} + \dot{\varepsilon}_{ij}^{p} + \dot{\varepsilon}_{ij}^{th} + \dot{\varepsilon}_{ij}^{pt} + \dot{\varepsilon}_{ij}^{tp}$$

  - **Elastic** rate
  - **Plastic** rate
  - **Thermal** rate
  - **Phase transformation** rate
  - **Transformation plasticity** rate

* Arif Sugianto, *et al. Journal of Materials Processing Technology*, 2009, 209: 3597-3609.

2 Methodology

Hardness prediction model

- Maynier model*

$$\mathbf{HV} = \xi_{\mathrm{M}}\mathrm{HV}_{\mathrm{M}} + \xi_{\mathrm{B}}\mathrm{HV}_{\mathrm{B}} + (\xi_{\mathrm{P}} + \xi_{\mathrm{F}})\mathrm{HV}_{\mathrm{F\text{-}P}}$$

$$\xi_{\mathrm{M}} + \xi_{\mathrm{B}} + \xi_{\mathrm{P}} + \xi_{\mathrm{F}} = 1$$

$$\mathbf{HV}_{\mathbf{M}} = 127 + 949\mathrm{C} + 27\mathrm{Si} + 11\mathrm{Mn} + 8\mathrm{Ni} + 16\mathrm{Cr} + 21\log V_{\mathrm{r}}$$

$$\begin{aligned}\mathbf{HV}_{\mathbf{B}} &= 323 + 185\mathrm{C} + 330\mathrm{Si} + 153\mathrm{Mn} + 65\mathrm{Ni} + 144\mathrm{Cr} + 191\mathrm{Mo} \\ &\quad + (89 + 53\mathrm{C} - 55\mathrm{Si} - 22\mathrm{Mn} - 10\mathrm{Ni} - 20\mathrm{Cr} - 33\mathrm{Mo})\log V_{\mathrm{r}}\end{aligned}$$

$$\begin{aligned}\mathbf{HV}_{\mathbf{F\text{-}P}} &= 42 + 223\mathrm{C} + 53\mathrm{Si} + 30\mathrm{Mn} + 12.6\mathrm{Ni} + 7\mathrm{Cr} + 19\mathrm{Mo} \\ &\quad + (10 - 19\mathrm{Si} + 4\mathrm{Ni} + 8\mathrm{Cr} + 130\mathrm{V})\log V_{\mathrm{r}}\end{aligned}$$

* P Maynier, *et al. Hardenability concepts with applications to steels*, AIME, New York, NY, 1978.

3 Numerical simulation

Geometry

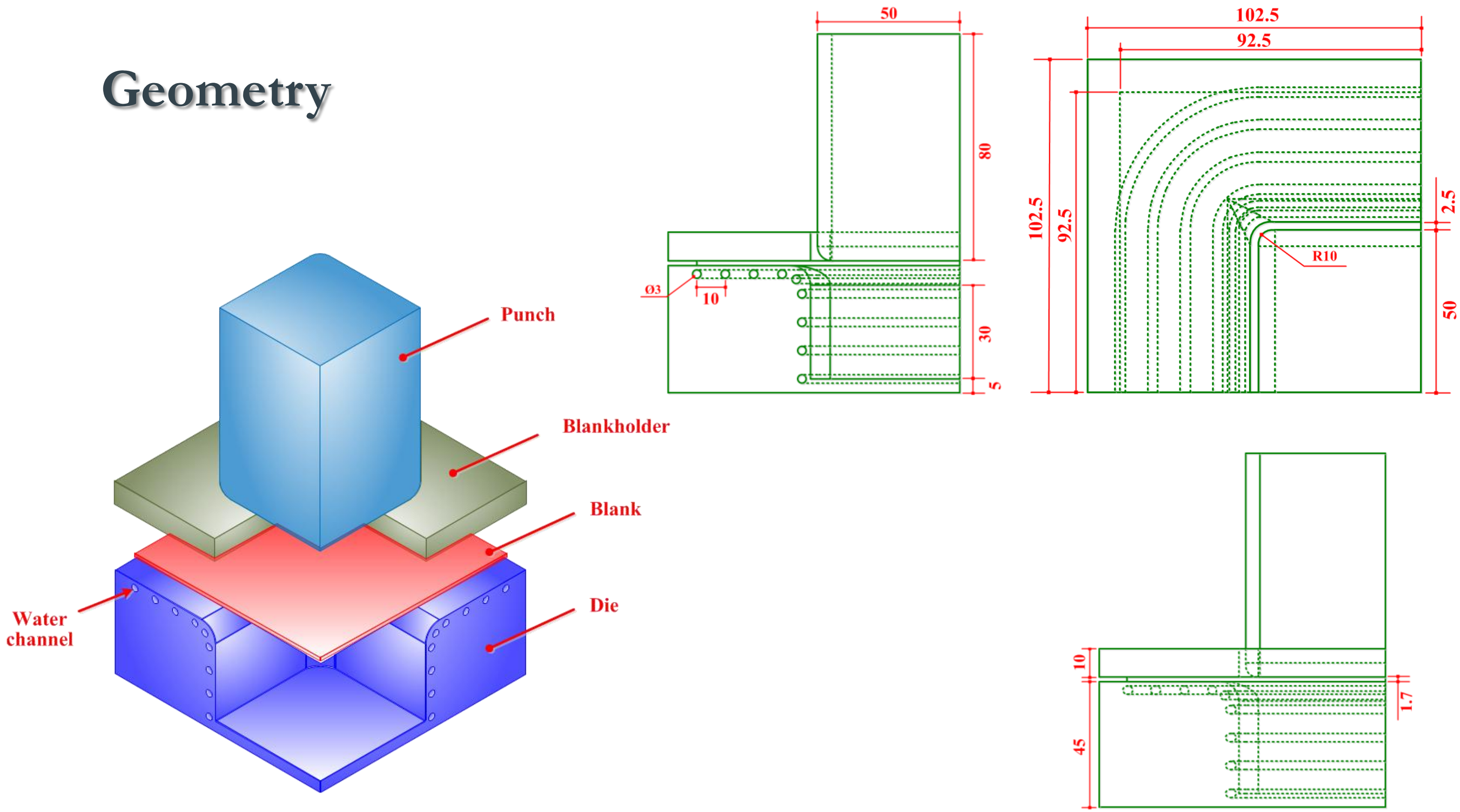


Fig.5 Geometry and dimension for hot stamping simulation.

3 Numerical simulation

FEM model

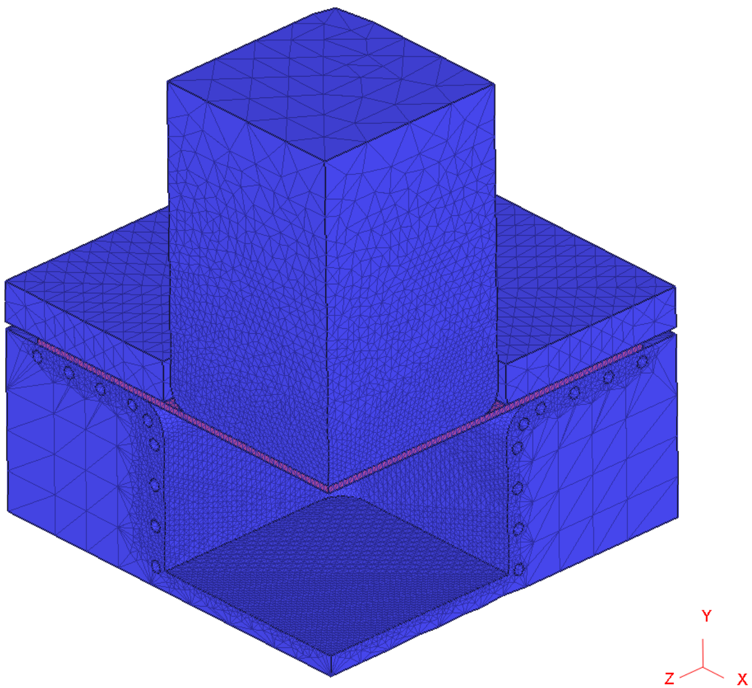


Fig.6 FEM model for hot stamping simulation.

- The velocity of water is 3.5m/s considered with a convective heat transfer coefficient of 15000w/(m^2•K).
- The brick and tetrahedral elements are used to discretize the blank and tools, respectively.
- The numbers of nodes and elements of tools are 55458 and 263932, while that of blank are 4418 and 2116.

3 Numerical simulation

Hot stamping process

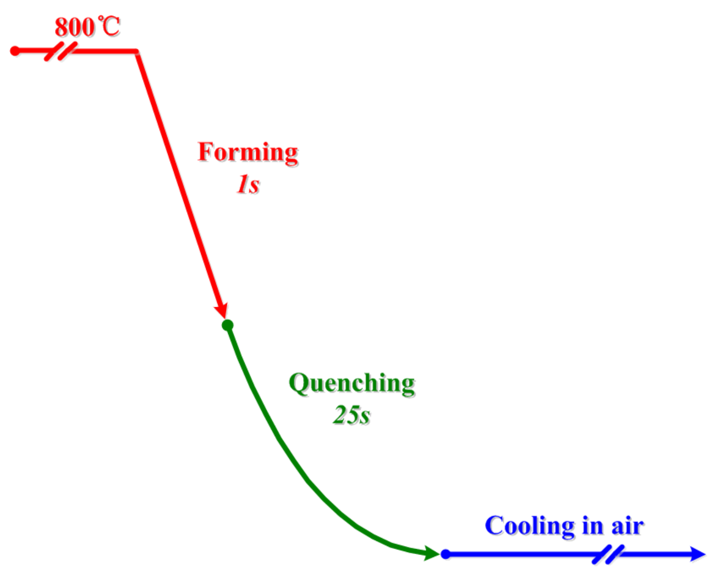
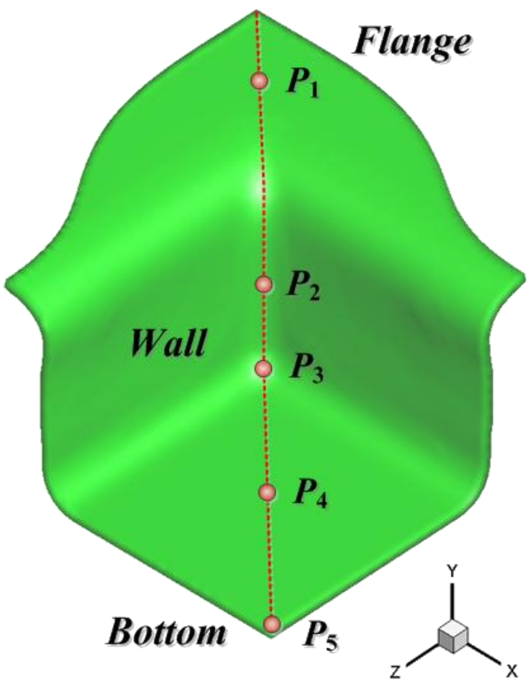


Fig.7 Illustration of hot stamping process.

- Firstly, the hot blank is transferred to the punching machine and formed.
- Subsequently, the forming component is holding in die for few seconds to make the microstructure of blank change into martensite completely.
- Finally, the component is ejected from the die and cooled by air.
- The initial temperatures of boron steel blank and tools are assumed as 800 ℃ and 25℃, respectively.

4 Results and analysis

Temperature evolution



- Five tracking points located in the flange, wall and bottom of box component (namely, P1, P2, P3, P4 and P5) are selected to monitor the temperature, microstructure evolution and hardness distribution during hot stamping process

4 Results and analysis

Temperature evolution

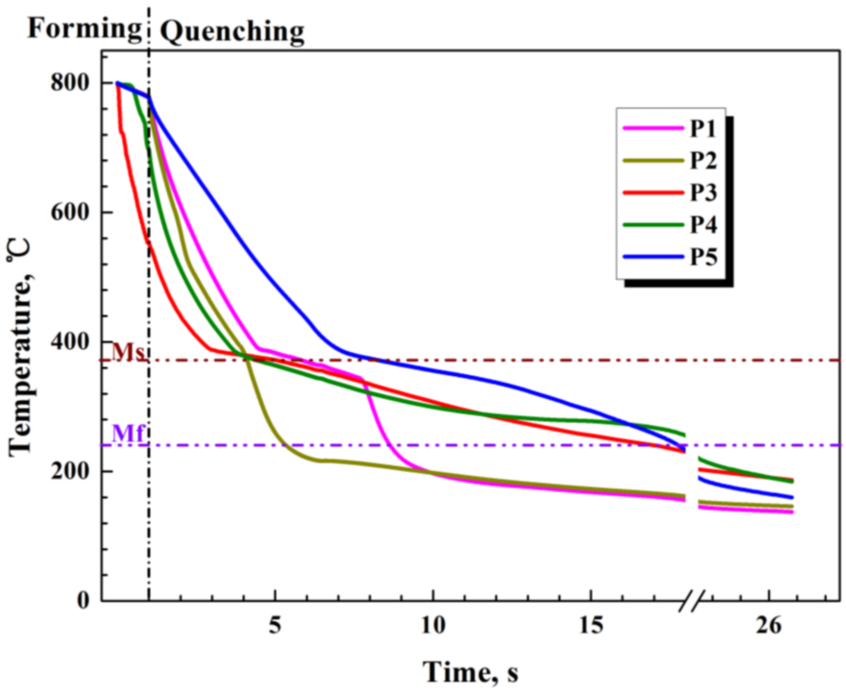


Fig.8 Time-dependent temperature curves of box component at different tracking points during hot stamping process.

- At the forming process, due to the direct contact between the blank and punch, P3 demonstrates a sharply decrease, while the temperature drop of other points is more gently.
- After 1s, the forming process is completed and entered the quenching process in die.
- About 3s later, P3 firstly occurs the martensitic phase transformation.
- Approximate 16s, all points has been achieve the martensitic finish temperature (Mf) and the component can be ejected and cooled by air.

4 Results and analysis

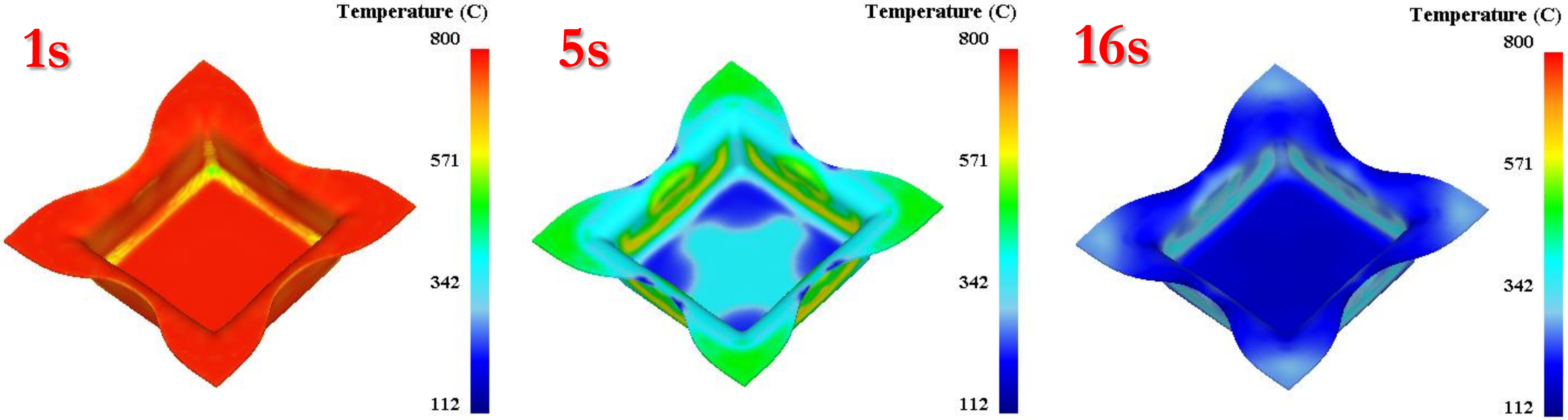


Fig.9 Temperature distribution of box component at different time.

4 Results and analysis

- After forming, the temperature at the bottom and flange almost uniformly (about 800℃), while at the bottom corner the lowest temperature is nearly 560 ℃.
- The contact condition had a significant influence on the temperature distributions.
- The gap between the blank and die causes a remarkable increase of heat exchange velocity.
- During quenching, the temperature of component decreases evidently and the maximum cooling rate takes place at the bottom.
- After quenching for 16s, the temperature of the entire component is lower than Mf and with a continuous uniform distribution.

4 Results and analysis

Microstructure evolution

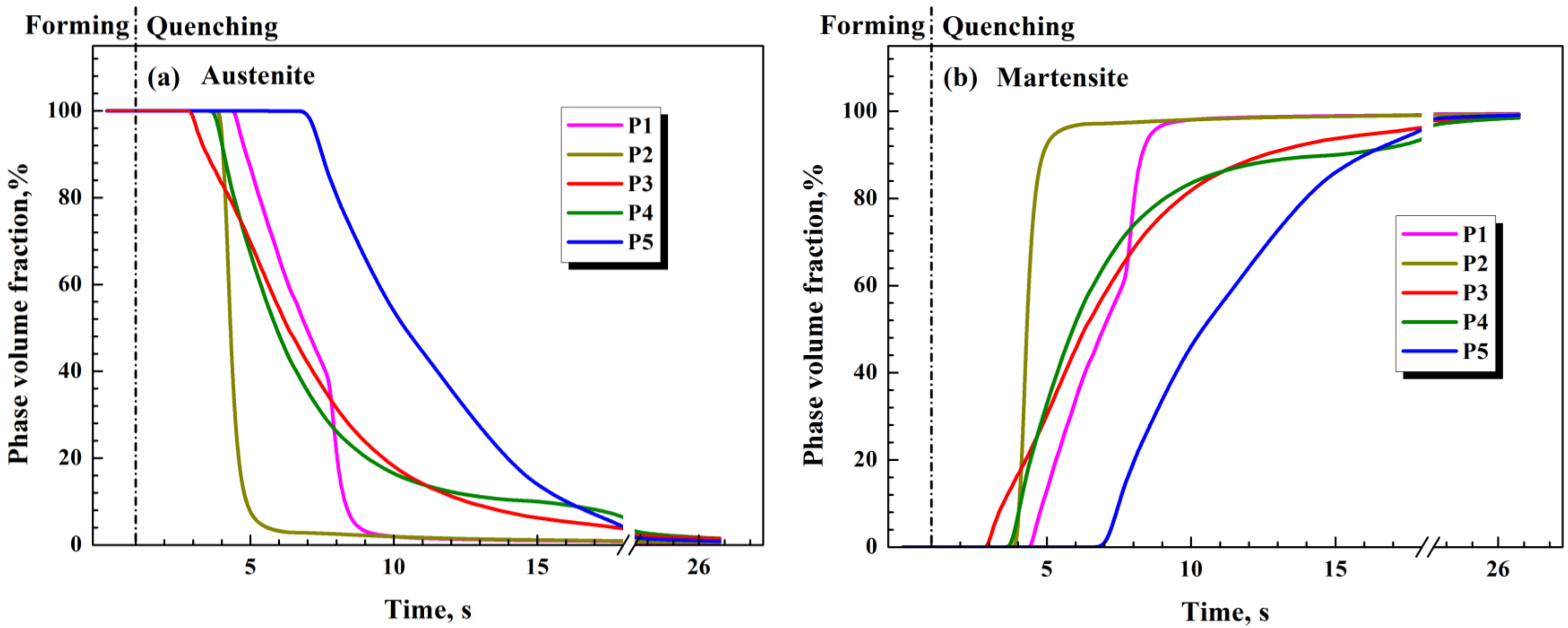
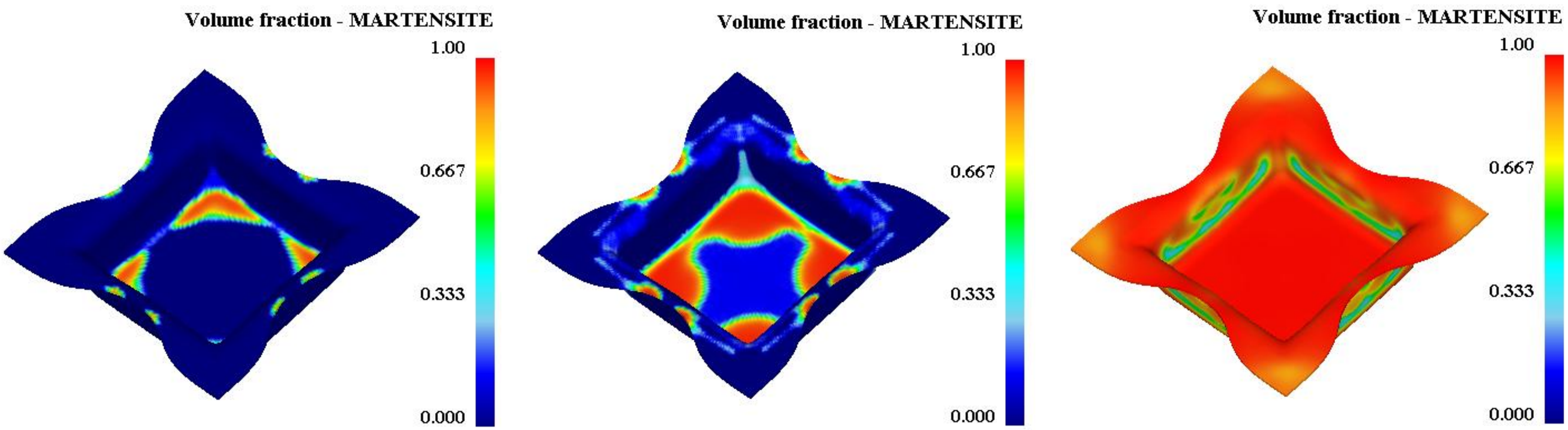


Fig.10 (a) Austenite and (b) martensite volume fractions of box component at different tracking points during hot stamping process.

4 Results and analysis

- After forming, the microstructure of component is still composed almost entirely of austenite.
- When the holding times have been enlarged to about 6s and 9s, the phase transformation from austenite to martensite at tracking points P2 and P1 are fully completed, respectively, while other tracking points need to last longer.
- After about 16s, the austenite volume fraction of component has been significantly decreased and finally its volume fraction is below 10%, while the martensite volume fraction has already gone beyond 90%.

4 Results and analysis



1s 5s 16s

Fig.11 Microstructure distribution of box component at different time.

4 Results and analysis

- Phase transformation from austenitic to martensite first takes place at the bottom corner of the formed component and subsequently progresses rapidly to the bottom and flange of component, which is in accord with the temperature evolution in formed component.
- The martensite volume fraction of component increases with the extension of holding time. When the time increases to 16 s, most of austenite has transformed into martensite.
- In contrast, the content of martensite at the wall of component is relatively lower, but the certain area in the wall with the minimum amount of martensite is also more than 60%.

4 Results and analysis

Hardness distribution

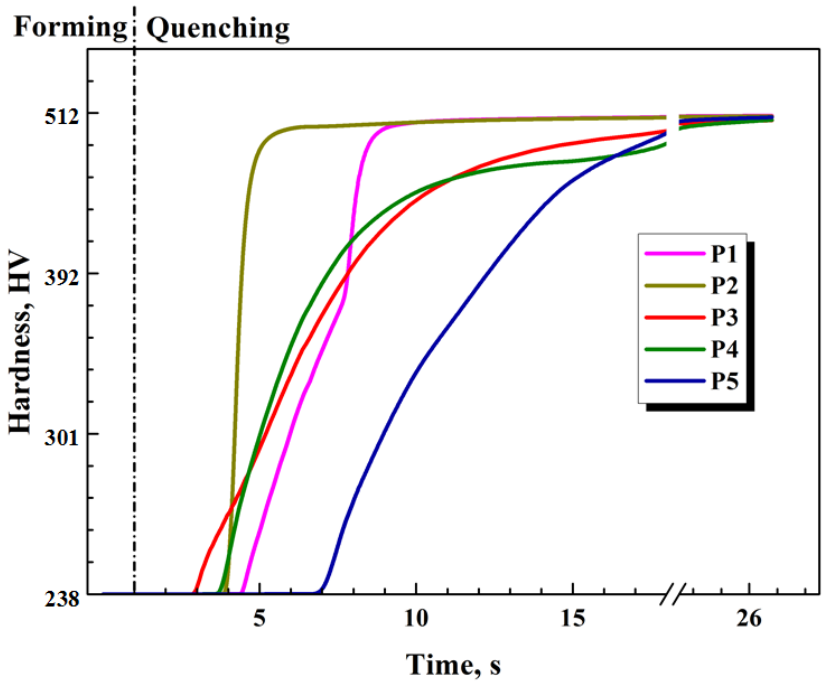


Fig.12 Hardness curves of box component at different tracking points during hot stamping process.

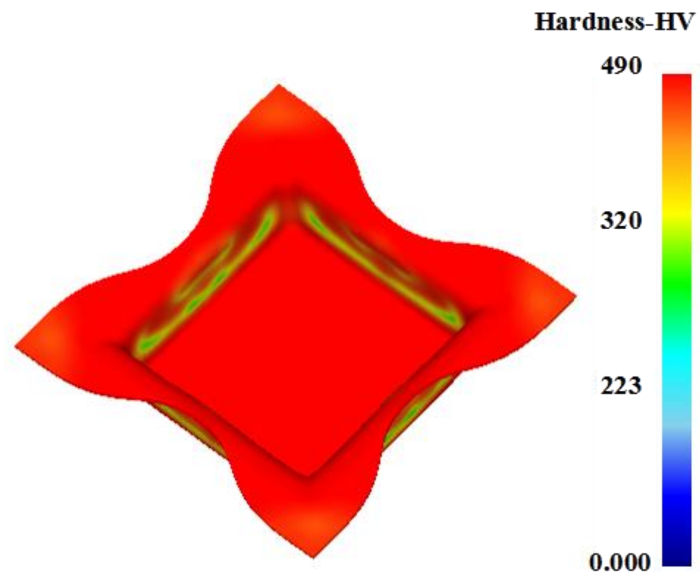


Fig.13 Hardness distribution of box component after hot stamping for 16s.

4 Results and analysis

- To satisfy the required hardness, the sufficient holding time of quenching in die is essential .
- As the holding time increases, the hardness in various regions of component shows a similar and distinct increasing trend. The predicted hardness of component after hot stamping is almost 512HV.
- After hot stamping for 16s, the hardness in the wall of component is lower than those in other locations due to its slower cooling rate.
- Except the wall of component, the component obtains a nearly uniform hardness of 500HV at the bottom and flange in the current cooling time.

5 Conclusions

- Considering the cooling system, the hot stamping process of 22MnB5 box component is successfully reproduced based on the metallo-thermo-mechanical theory, which can provide a theoretical guidance for optimizing the hot stamping procedure.
- To satisfy the required mechanical properties of formed component, the sufficient holding time of quenching in die is essential and it plays an important role in ensuring the required hardness.
- The predicted hardness of component after stamping is almost 512HV and it shows a good agreement with the experimental results.

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Thank you！

- Liu Yonggang PH. D.
- Auto Sheet Strategic Business Unit Maanshan Iron & Steel Co.,Ltd., Maanshan, China
- Add.：CiHu New District, Maanshan City, Anhui Province, China
- Tel.：0555-2871101
- Fax：0555-x2871101
- E-mail：lyghotmail@hotmail.com