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Numerical modeling and experimental study of microstamping process for fabricating microchannels using thin sheets of titanium

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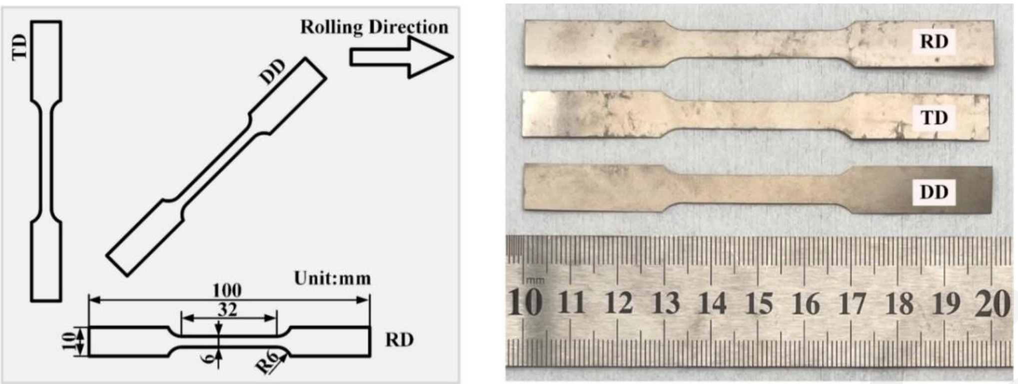
Constitutive Modeling



(a) (b)

Fig. 1 The tensile testing specimens

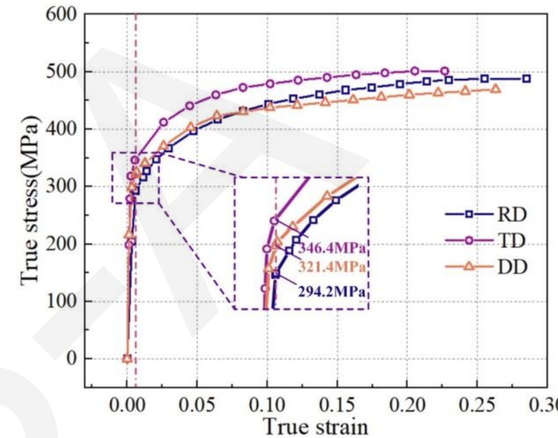


Fig. 2 The true stress-true strain curves

Off-axis elastic modulus

$$E_x(\theta) = \frac{1}{\bar{S}_{11}} = \left[\frac{1}{E_1} m^4 + \left(\frac{1}{G_{12}} - \frac{2\nu_1}{E_1} \right) m^2 n^2 + \frac{1}{E_2} n^4 \right]^{-1}$$

Hill's yield criterion

$$\bar{\sigma} = \sqrt{(G+H)\sigma_1{}^2 + (F+H)\sigma_2{}^2 - 2H\sigma_1\sigma_2 + 2N\tau_{12}{}^2}$$

least squares method

	F	G	H	N
LS method	0.2035	0.3542	0.5306	1.4096

Voce hardening law

$$\sigma = s + A(1 - e^{-m\varepsilon_p})$$

stress-strain relationships

$$\sigma(\theta) = \begin{cases} \varepsilon \cdot E_x(\theta), \varepsilon < \dfrac{\sigma_s(\theta)}{E_x(\theta)} \\ \sigma_s(\theta) + 169.94 \left[1 - e^{-23.44\left(\varepsilon - \frac{\sigma_s(\theta)}{E_x(\theta)}\right)} \right], \varepsilon \geq \dfrac{\sigma_s(\theta)}{E_x(\theta)} \end{cases}$$

Constitutive Modeling

- For the Hill's criterion using the least-squares method, the maximum error in the prediction of the yield stress occurs in the RD specimen with 6.3%.
- In the hardening stage, the RD and DD specimen curves are close to each other, and the maximum error occurs in the DD specimen with 8.3%.

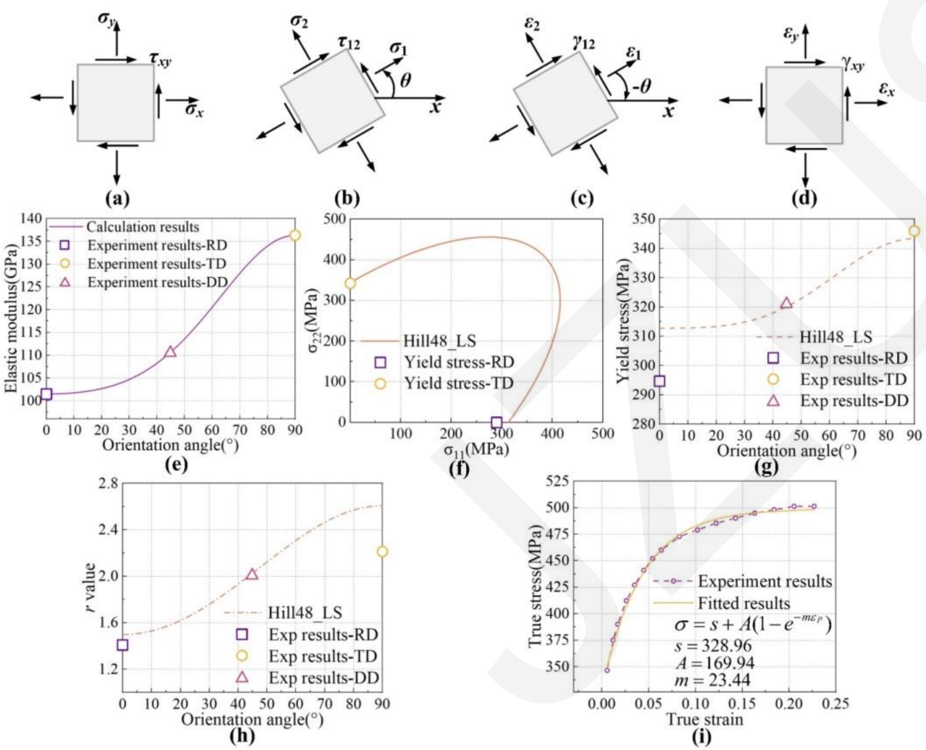


Fig. 3 Establishment of constitutive model

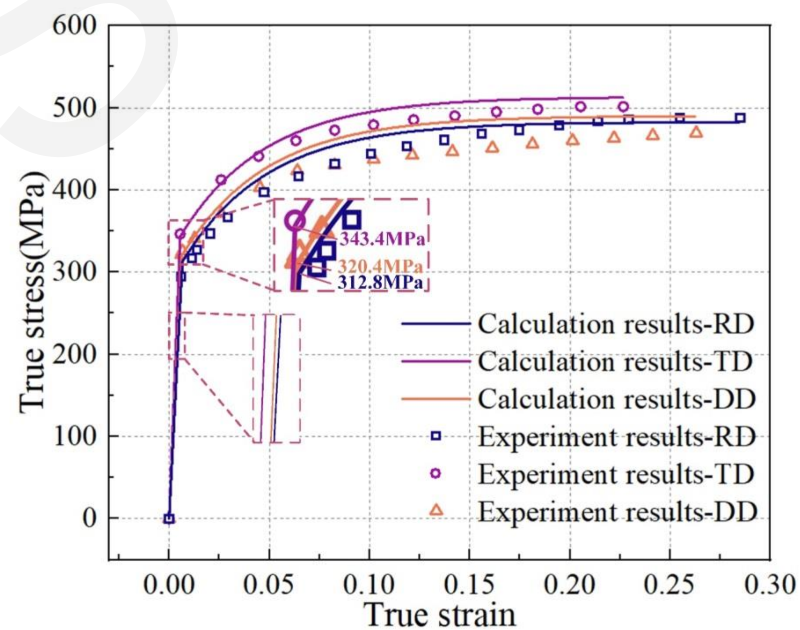


Fig. 4 The comparison of experimental and calculated true stress-true strain curves

Experimental Setup and Procedure

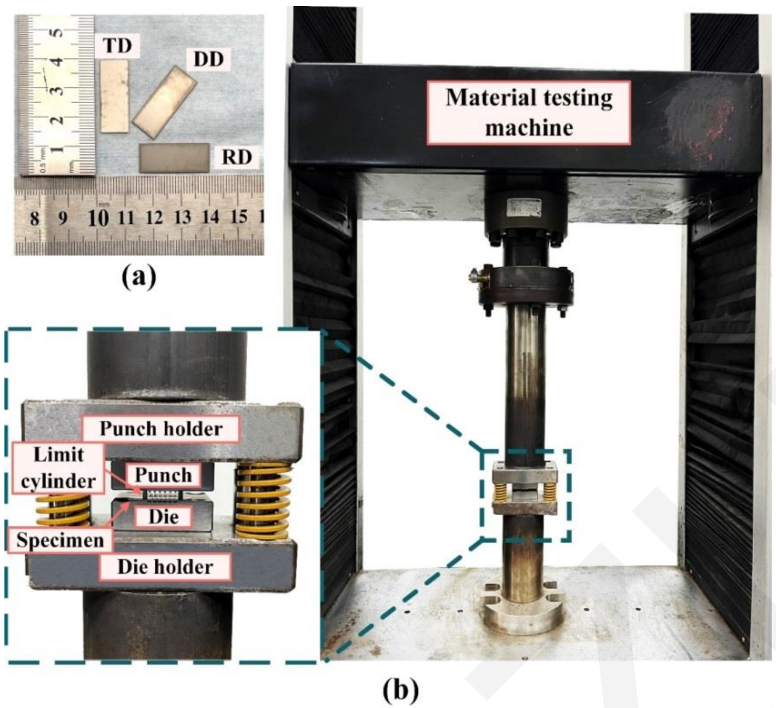


Fig. 6 Experiment of microstamping process

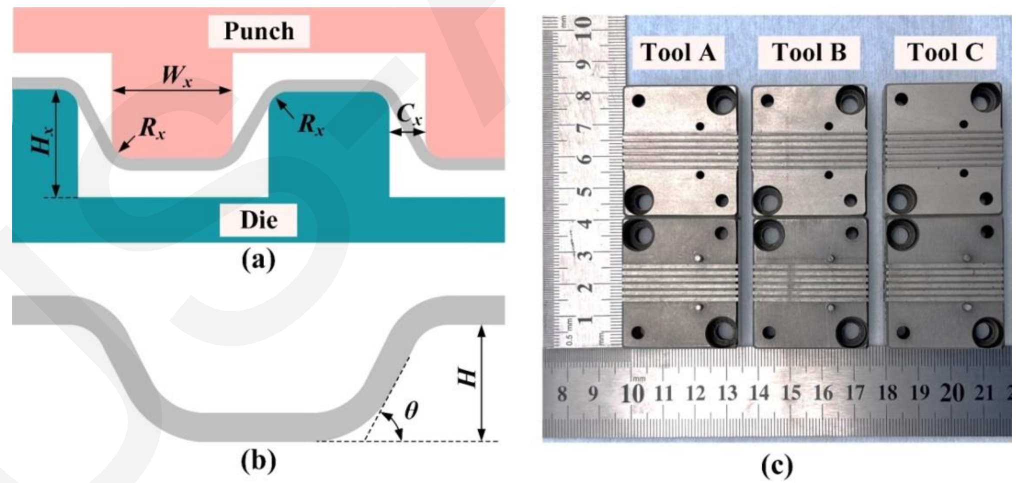


Fig. 7 Schematic diagram of process parameters and tool dimensions

Microstamping experiments were conducted on the INSTRON 5966 material testing machine. Three sets of tools were selected for model verification and manufacturing forming experiments.

Results and Discussion

■ Verification of Model

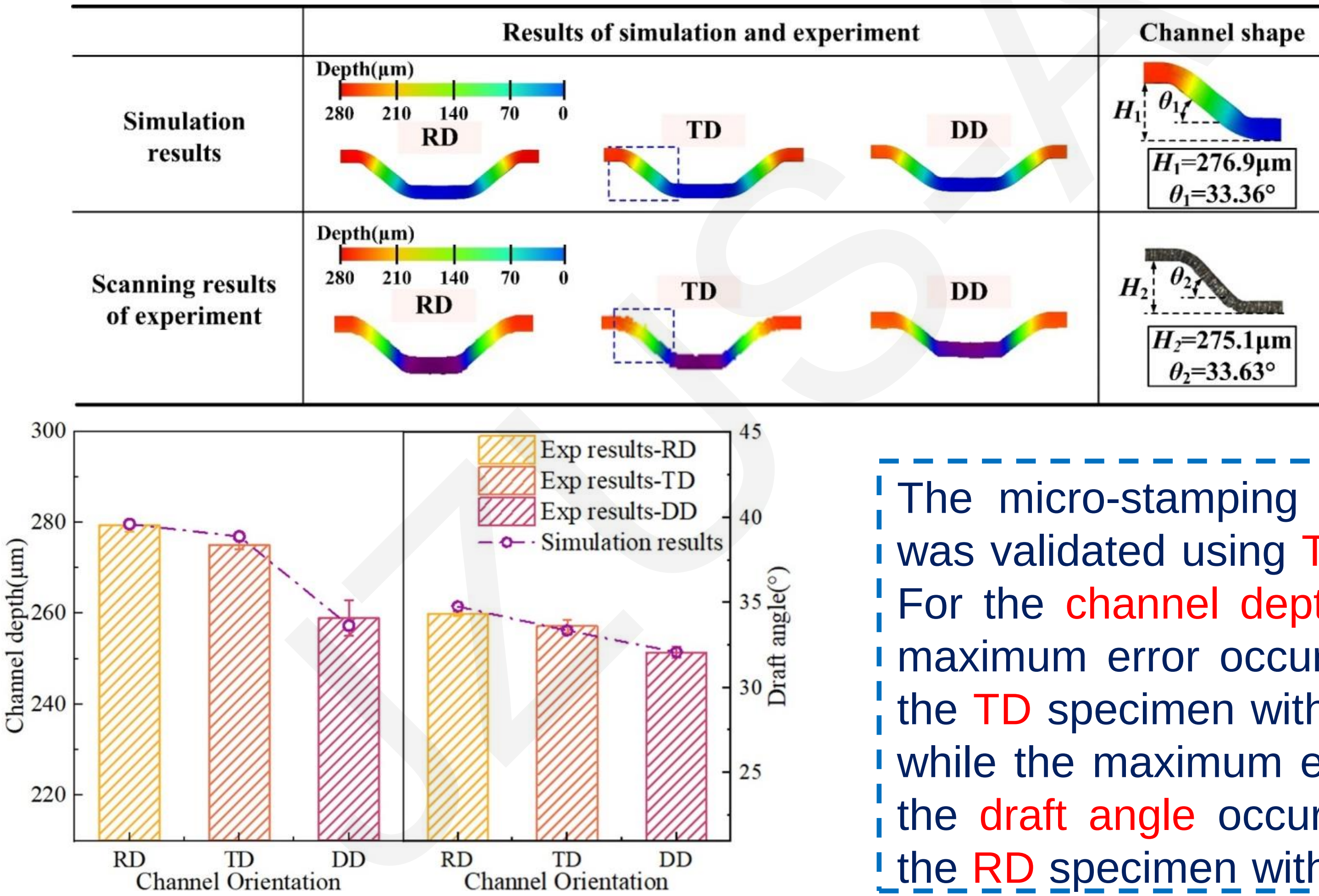


Fig. 12 Simulation and experiment results of microstamping

The micro-stamping model was validated using Tool A. For the channel depth, the maximum error occurred in the TD specimen with 0.7%, while the maximum error in the draft angle occurred in the RD specimen with 1.2%.

Results and Discussion

■ Simulation Results of Microstructures Stamping

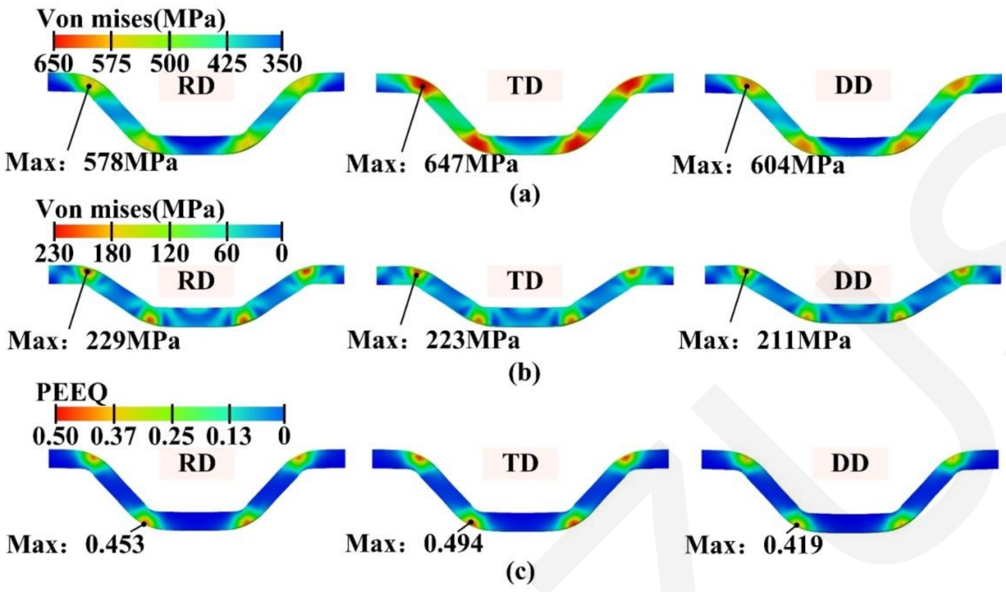


Fig. 8 The distribution of stress and plastic strain with different orientations under different microstamping stages

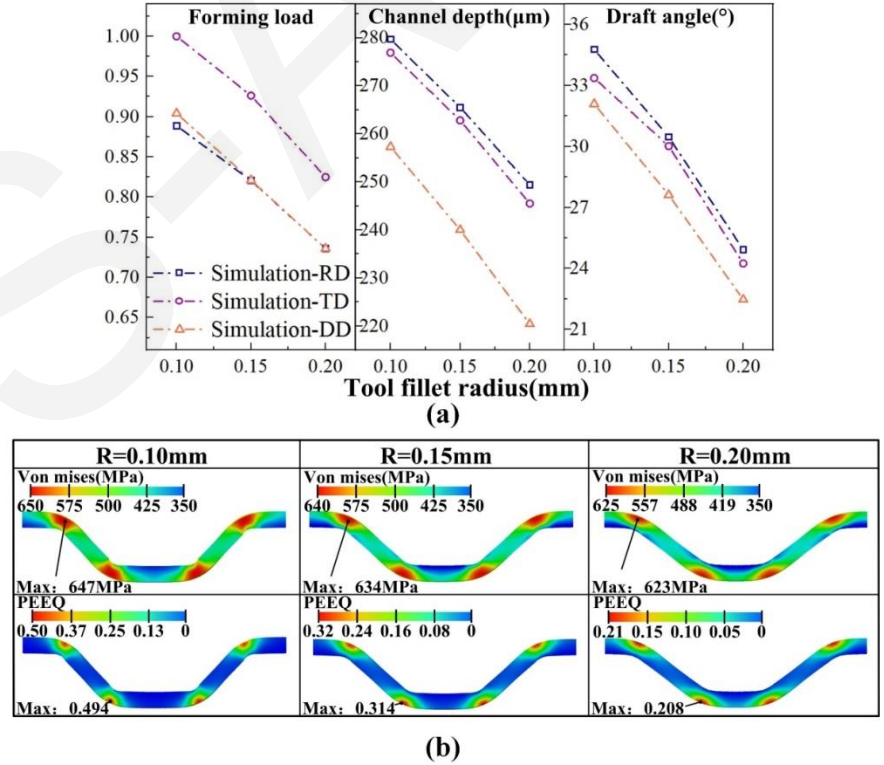


Fig. 9 Effects of tool fillet radius

- We explain the springback anisotropy of titanium sheet during microstamping from the stress and strain analysis.
- Compared to tool clearance and punch width, the decrease in tool fillet causes a greater depth increase and a milder stress concentration.

Results and Discussion

■ Microstructures Manufacturing Result

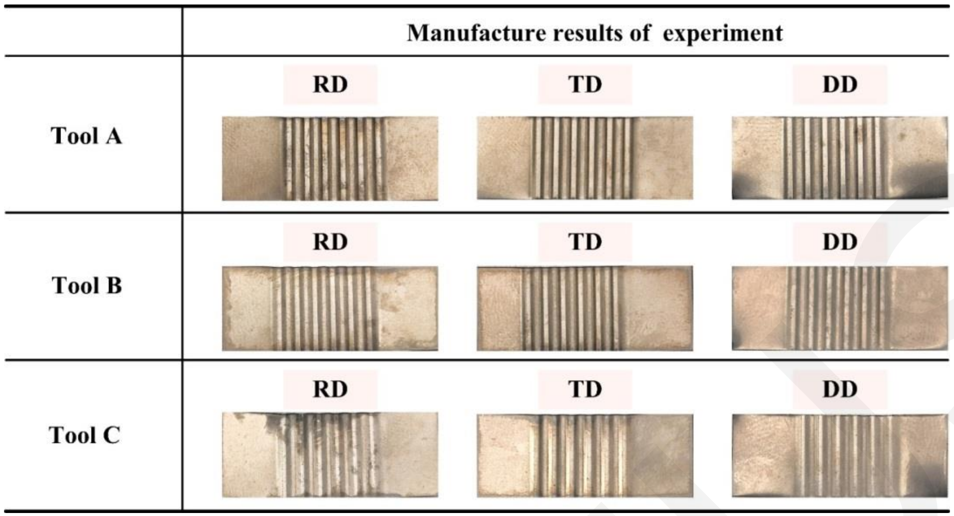


Fig. 13 Microchannels fabrication results

Central channels' depth and draft angle are less than edge channels'. Due to the anisotropy, the RD channel has minimal springback. We chose RD channel with 0.1mm fillet radius to fabricate channels with 279.3 μm depth and 34.34° draft angle.

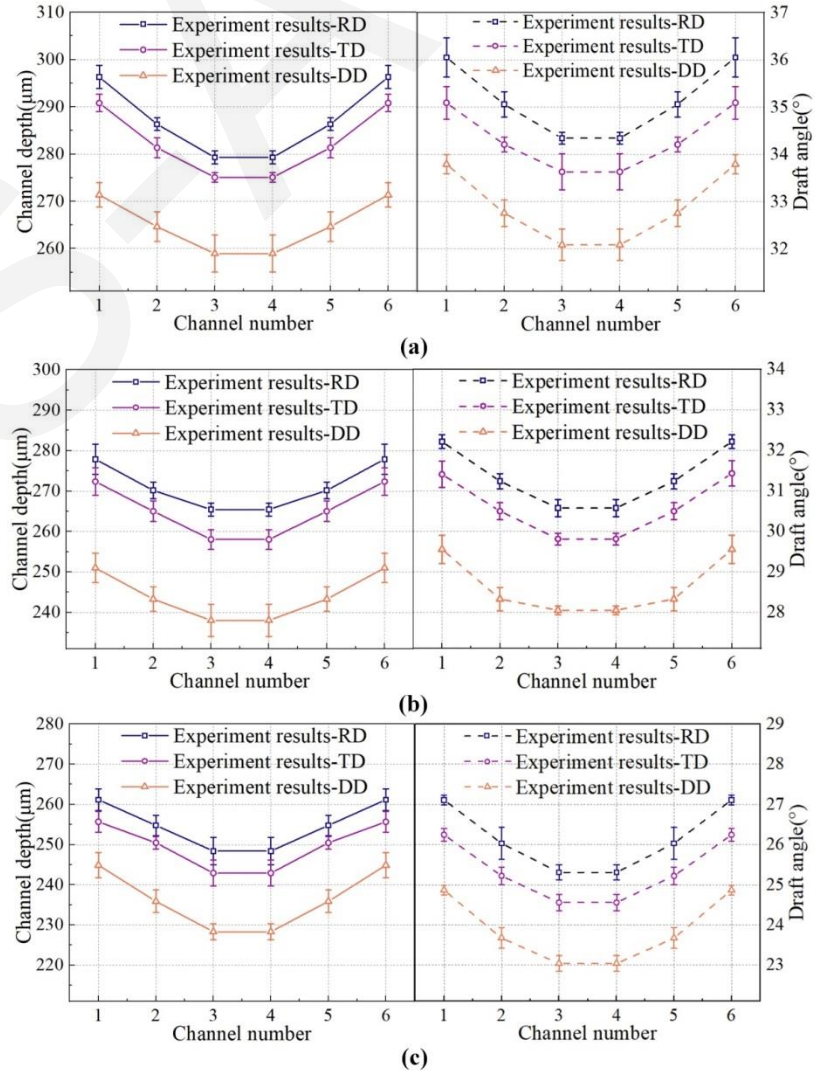


Fig. 14 The measured evaluation indicators

Conclusions

- The orthogonal constitutive model can accurately predict the elastic-plastic behavior of titanium sheet and the microstamping simulation model can accurately predict springback.
- The anisotropy of titanium sheet in microstamping processing leads to different degrees of forming load and springback for specimens with different orientations
- Channels with a depth of 279.3 μm and a draft angle of 34.34° was fabricated by selecting RD specimens and a tool with a fillet radius of 0.10 mm.