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A study of 3D finite element modeling method for stagger spinning of thin-walled tube

Key words: stagger spinning, 3D-FE modeling, roller interval

Model Construction

- 1 ● Develop a modified 3D-FE model of stagger spinning to improve current defects

Model analysis

- 2 ● Investigate influences of problems including the precision mode, time truncation, boundary mode, interference phenomenon, and so on

Model application

- 3 ● Make some improvements of current reported results of roller intervals,, with higher accuracy and reliability, based on the modified model.

Research process of modeling method for stagger spinning

Model Application

Influence of roller intervals without interference

Strain distribution

Roller force

Wall thickness.

Model Analysis

Influence of key modeling problems

Boundary mode

Time truncation

Precision mode

Interference phenomenon

Model build

Base Configuration

Model extraction

Grid generation

Material properties

Boundary condition

Contact surface and pair

Models Specification

Mechanical model

Frictional model

Contact model

Model Verification

Grid independency

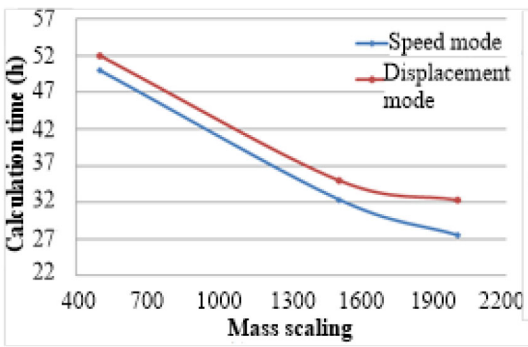
Energy criteria

Strain variation

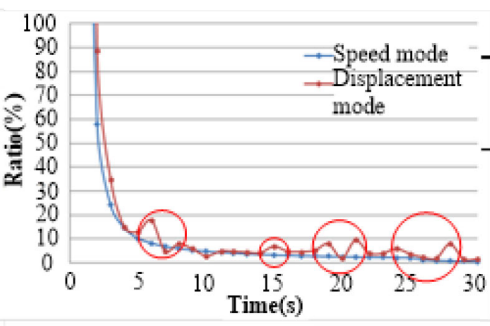
Swelling size and uplift coefficient

Results and Conclusions

Speed mode is superior to displacement mode in simulation accuracy and stability.



Calculation efficiency

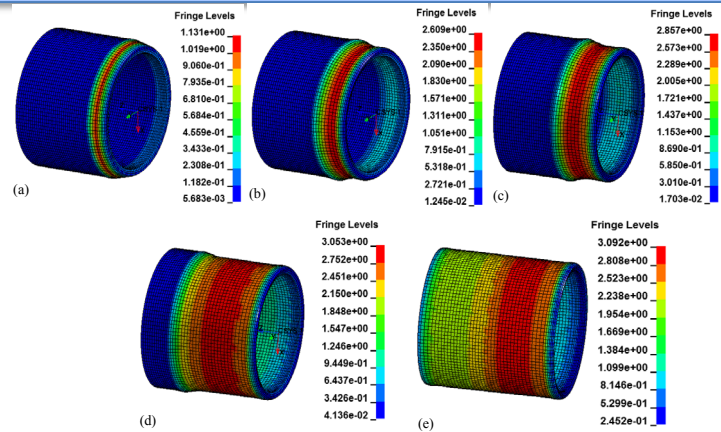


Energy parameters

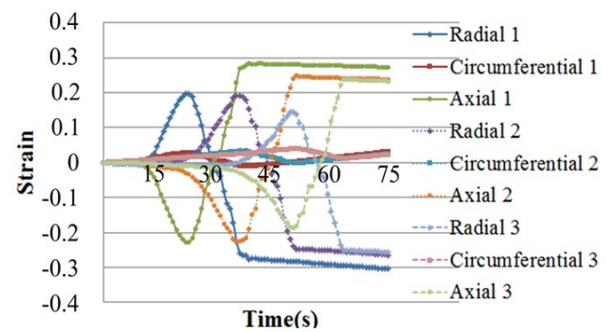
Swelling size and uplift coefficient

| α (°) | E_{ssz} | E_{uct} | S_{ssz} | | S_{uct} | | Err_{ssz} (%) | | Err_{uct} (%) | |
|--------------|-----------|-----------|-----------|--------|-----------|--------|-----------------|--------|-----------------|--------|
| | | | $D-s$ | $Sp-s$ | $D-u$ | $Sp-u$ | $D-s$ | $Sp-s$ | $D-u$ | $Sp-u$ |
| 20 | 0.2 | 0.0 | 0.2 | 0.267 | 0.029 | 0.031 | 8.9 | 4.6 | 9.6 | 4. |
| | 8 | 33 | 55 | | 8 | 4 | 2 | 4 | 9 | 85 |
| 25 | 0.2 | 0.0 | 0.2 | 0.227 | 0.027 | 0.028 | 8.3 | 5.4 | 7.6 | 5. |
| | 4 | 3 | 2 | | 7 | 3 | 3 | 2 | 7 | 83 |
| 30 | 0.1 | 0.0 | 0.1 | 0.181 | 0.025 | 0.026 | 11. | 4.7 | 8.5 | 5. |
| | 9 | 28 | 68 | | 6 | 4 | 57 | 4 | 7 | 71 |
| 35 | 0.1 | 0.0 | 0.1 | 0.104 | 0.038 | 0.039 | 8.1 | 5.4 | 8.0 | 5. |
| | 1 | 42 | 01 | | 6 | 8 | 8 | 5 | 9 | 24 |

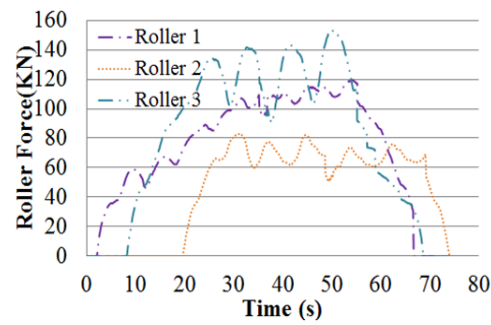
Time truncation is an undesirable option for analysis of the distribution trend of time-history parameters to guarantee the data has reached the stable state.



Variations of strain under different time process: (a) 5 s, (b) 10 s, (c) 15 s, (d) 35 s, and (e) 70 s



(a)

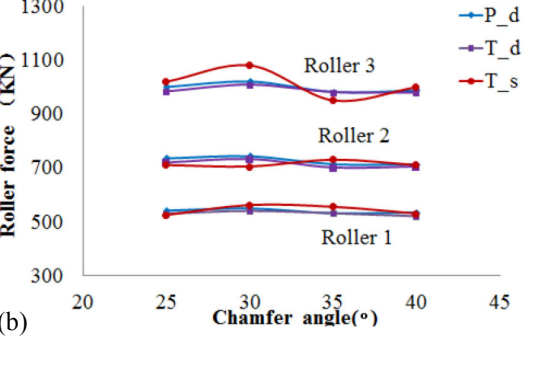
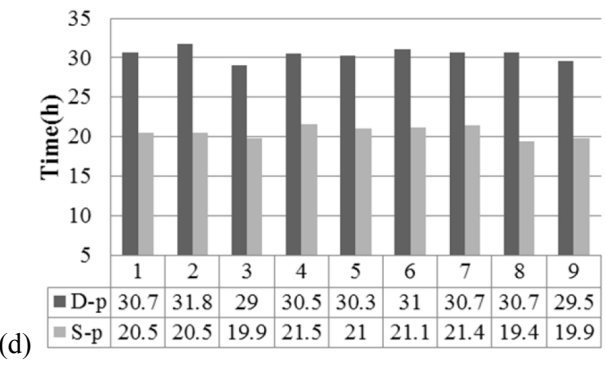
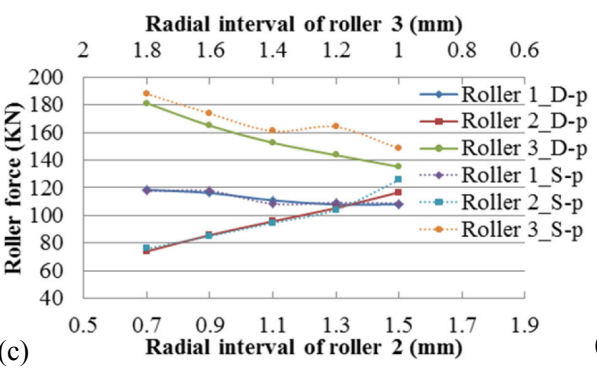
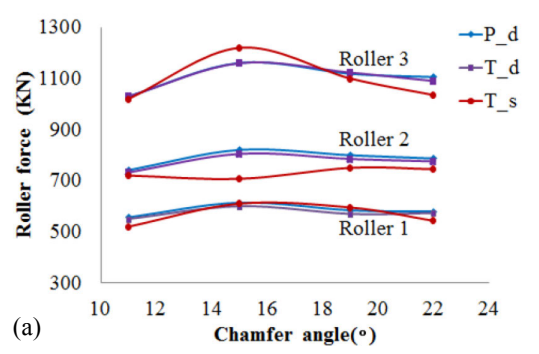
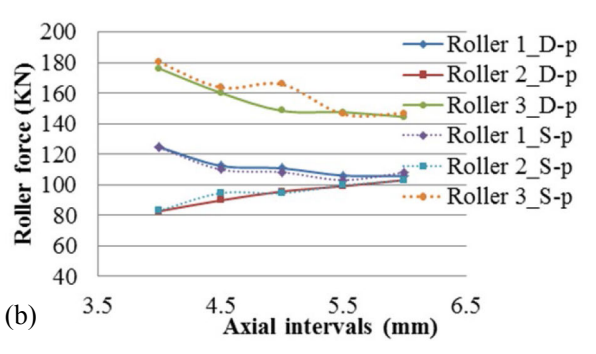
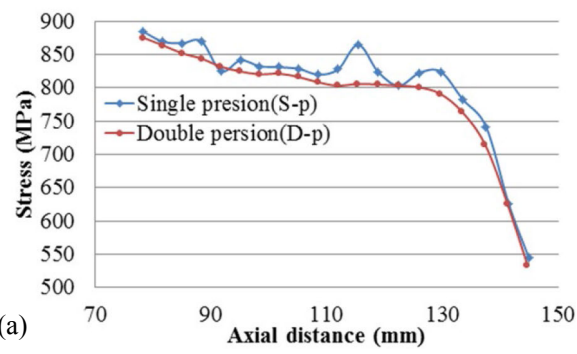


(b)

Variations of strain of three axial elements (a) and (b) roller forces

Results and Conclusions

Double precision mode is more suitable for stagger spinning simulation, as truncation error has obvious effects on the accuracy of results

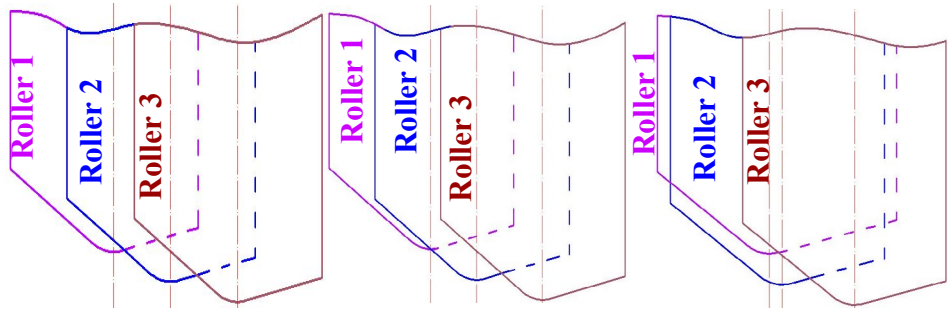


Comparison of the variations of (a) stress and roller force with (b) axial and (c) radial intervals and (d) time consumption of precision model

Comparisons of the variations in roller force changing with chamfer angle: (a) group 2.1 and (b) group 2.2 of Ge et al. (2014) under single and double precision

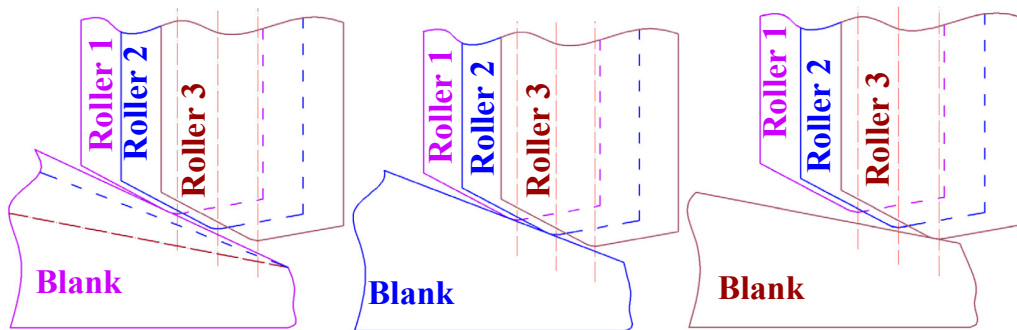
• Results and Conclusions

• If one roller does the wall thickness reduction work of the others due to the inappropriate setting of the roller intervals and inclination angle of rollers and blank, interference phenomenon occurs



Process of position interference phenomenon (PIP):
 (a) normal case, (b) critical case of PIP, and (c) case of PIP
 (Ge et al., 2014).

- As shown in left fig, the normal order for the contacting blank is roller 1, 2, 3.
- With the decrease of roller intervals, roller 2 is about to enter the thinning area of roller 1, as shown in Fig. (b).
- When roller 2 enters the area of roller 3, as shown in Fig. (c), the contact order turns to roller 2, 1, 3, and position interference phenomenon (PIP) occurs since roller 2 carries out the wall thickness reduction work of roller 1 because of inappropriate roller intervals (Ge et al., 2014).

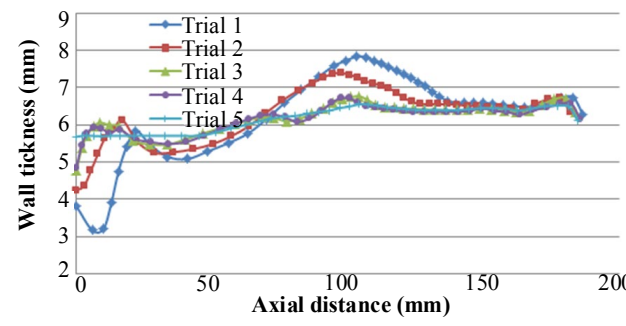
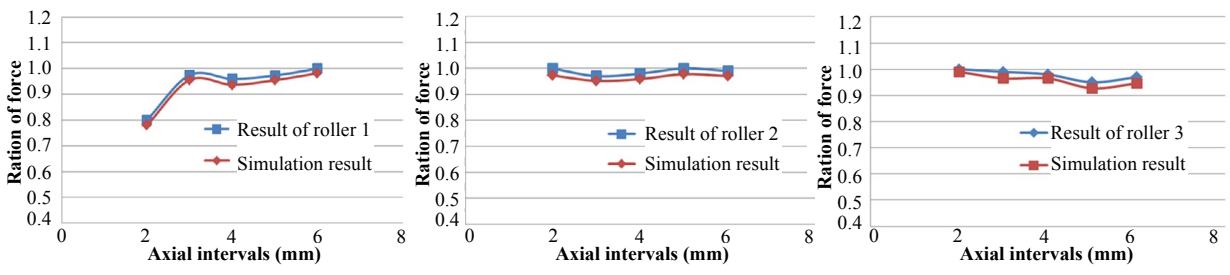


Process of inclination interference phenomenon (IIP):
 (a) normal case, (b) critical case of IIP, and (c) case of IIP
 (Ge et al., 2014)

Inappropriate inclination angle of the rollers or the blank also will lead to the inclination interference phenomenon (IIP). As shown in left fig, if the chamfer angle of blank decreases, the contact order of roller 1, 2, 3 (Fig. a) will turn to 3, 2, 1, and then IIP occurs (Fig. c) (Ge et al., 2014).

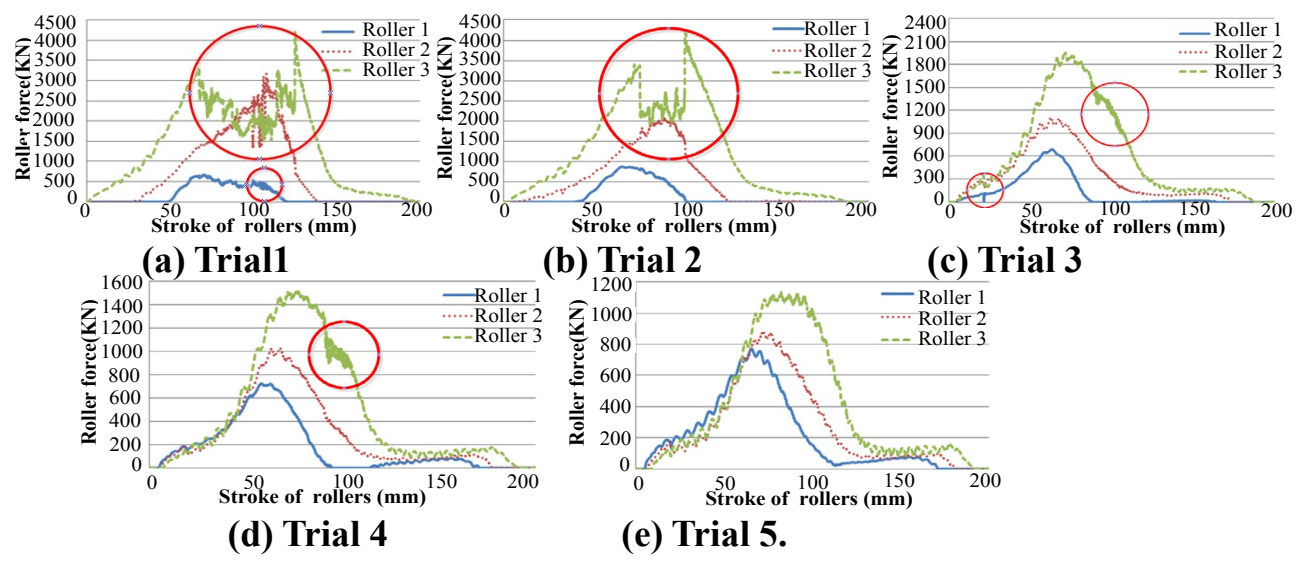
Results and Conclusions

Interference phenomenon can lead to obvious oscillation and mutation simulation results and influence the reliability of simulation significantly



Comparison of the simulation results with those of Li et al. (2013) on the ratio of axial force to radial force

(a) Wall thickness



(b) Cross sections of each trial

Wall thickness variations under full simulation situation.

Variations of roller force of each designed trial under full simulation situation

• Results and Conclusions



Influence of modeling method on the simulation process
 ("+": positive; "-": negative, C :‘Convenience’, E : ‘Efficiency’, A : ‘Accuracy’, and S : ‘Stability’)

| Model characters | | Influence | | | |
|-----------------------------------|---------------------------|-----------|-----|-----|-----|
| | | C | E | A | S |
| Geometry | Part model | + | + | - | - |
| | Full model | | - | ++ | ++ |
| Grid type and independency | Tetrahedron elements | + | - | - | - |
| | Hexahedral elements | - | + | ++ | + |
| Boundary mode | Displacement mode | + | - | - | - |
| | Speed mode | - | + | + | ++ |
| Precision mode | Single precision | + | + | - | - |
| | Double precision | - | - | ++ | ++ |
| Simulation time | Time truncation | - | + | - | - |
| | Full simulation | - | — | ++ | ++ |
| Interference | Existence of interference | | - | - | - |
| | Exclusion of interference | - | +++ | +++ | +++ |

• Results and Conclusions

**Influence of roller intervals on the simulation forming results without IP.
(Roller—R; Difference between roller—Dif; Beginning areas—BA ; Ending areas —EA; wall thickness fluctuation, reduction and minimum wall thickness—WF, WR, MW).**

| | Trend of intervals | Trend of roller force | | | | | BA | | | EA | | |
|--------------------------|--------------------|-----------------------|----|----|---------|---------|----|----|----|----|----|----|
| | | R1 | R2 | R3 | Dif 1,2 | Dif 1,3 | WF | WR | MW | WF | WR | MW |
| Axial interval C | ↑ | ↓ | ↑ | ↓ | ↓ | ↑ | ↓↑ | | | | | ↑ |
| Radial interval I | ↑ | | | | | | | | | | | |
| Radial interval I | ↓ | ↓↑ | ↑ | ↓ | ↓↑ | ↓↑ | | ↓ | | | | ↓ |

The trends of wall thickness variations are similar, the thinning ratio of wall thickness decreases gradually with the increase of Δt_2 and decrease of Δt_3 . With the increase of axial intervals, the minimum wall thickness increase gradually