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Simulation and Experiment Research on Deforming Force of Slab Cold Roll-beating

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Abstract: Firstly, the principle of slab cold roll-beating is simply described. Then finite element model of slab cold roll-beating is established with ABAQUS and the simulation is completed. According to the simulation results, the changes of deforming force and the influence of technological parameters on the deforming force are analyzed. Finally, in combination with cold roll-beating experiments, the comparative analysis between the simulation and the experiment results is completed to test the validity of the finite element model. *Copyright © 2012 IFSA.*

Keywords: Cold roll-beating; Deforming force, Finite element simulation, Technological parameter, Experimental study.

1. Introduction

With the increasingly drastic marketing competition and fast updating of products, many drawbacks such as long time production preparation, equipment of large tonnage, poor processing flexibility and high manufacturing costs by the traditional die forming process are reflected day by day [1]. In order to adapt to the market demand of the rapid product updating in modern manufacturing field, many scholars committed to the new dieless (or flexible die) precise plastic forming process combining with high speed and efficient. Because of the features of its dieless unconstrained, partial load and low energy consumption, single point cumulative incremental forming has become increasingly attractive as new precise plastic forming technology [2-5].

High speed cold roll-beating is of great concern as dieless unconstrained incremental forming technology. During the initial research period, the exploration for the forming principle, finite element analysis, dynamic simulation and prototype equipment are conducted [6-8], which verified the feasibility of the cold roll-beating forming process, but further detailed study is still needed to get the variation of the deforming force which affects the metal flow mechanism and geometry of the forming surface.

Deforming force of cold roll-beating directly affects metal flow of forming process, thereby affecting geometry of the forming surface, and will influence part quality finally. Thus, deforming force plays an important role in the research of cold roll-beating forming as a key factor affecting forming mechanism and precision [4, 5].

In this paper, ABAQUS is applied to simulate the forming process of cold roll-beating. Combined with experimental study, changes of deforming force in forming process and the effects of process parameters on the deforming force are revealed which not only provide the basis for the select of process parameters and the control of forming process, but also lay theoretical and applied foundation for further study on high-speed cold roll-beating of function surface and the technique of single point dieless unconstrained accumulation forming.

2. Principle of Cold Roll-beating

High speed precision cold roll-beating is typical of precise plastic forming technology. In the forming process, by taking advantage of the inherent plasticity of rough material at ordinary temperatures, the roller with certain shape and high speed rotation, roll-presses and beats the rough blank intermittently, forcing the local metal of the rough surface flow, plastic deformations of continuous accumulate to form the profile of the required part [8].

The working principle of slab cold roll-beating is shown in the Fig. 1. The rollers of certain shape are mounted on a rotating shaft with high speed evenly. In the cold roll-beating forming, slab blank feeds horizontally; the rollers with high speed rotation beat the slab blank intermittently; metal materials of slab blank surface move a certain displacement due to high speed impact of the rollers. The roller rotates around its own axis the moment the roller contacts with the slab because of the action of the friction between them, thereby the rolling between the roller and the slab is ensured. The action is repeated until the specific shape is formed eventually in the slab blank to satisfy the predetermined depth of cut (rolling reduction).

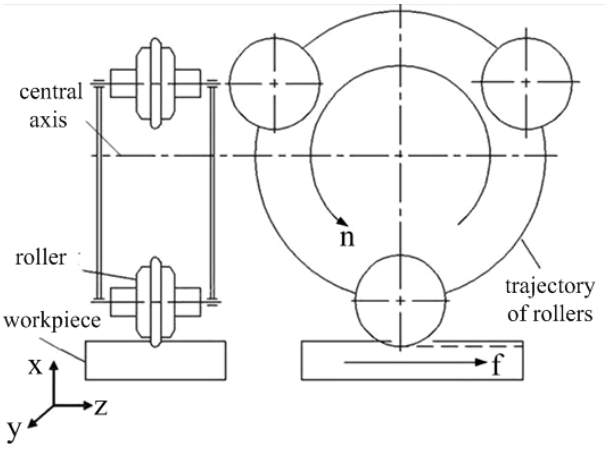


Fig. 1. Principle of slab cold roll-beating forming.

According to the direction of metal flow, the deforming force of cold roll-beating is divided into CFN_X, CFN_Y and CFN_Z. The paper focuses on the changes of radial deforming force (CFN_X), and the effects of process parameters (rolling reduction, feed rate and different speed) on the deforming force.

3. Slab Cold Roll-beating FEA Model

To ensure that the numerical simulation goes smoothly and computational efficiency, it is necessary to simply FEA model and initial conditions. The influence of the roller rotation is ignored, and only the roller model used to cold roll beating forming the roll tooth is established [9]. The deformation body blank adopts the square slab. The material is 45# steel.

When meshing, the roller is bound into a rigid body, and its own deformation is ignored. As the plastic deformation body the slab blank adopts the element type of C3D8R. The high density meshing method is selected in the contact area between the roller and the blank. The surface to surface contact between the rigid body and the deformation body is applied to define the contact of the roller and the blank [10, 11]. For the boundary conditions, the blank bottom is restricted and only the constant feeding velocity in the forward direction is maintained. While dealing with the roller constraints only the quality characteristic and the moment of inertia in the coordinate are given to its reference point, three translational degrees of freedom and the x- and z- rotational degrees of freedom are restricted, and its y- constant revolution speed is defined. The final finite element simulation model is shown in the Fig. 2.

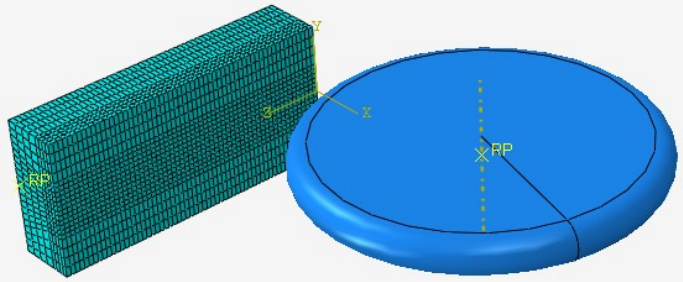


Fig. 2. Finite element model of cold roll-beating shaping.

4. Analysis of Deforming Force Simulation

According to the simulation results, the change of deforming force is analyzed, the single factor testing program is applied to study the influence of the process parameters such as rolling reduction, feed rate and rolling speed to the deforming force.

4.1. Changing Law of Deforming Force in Cold-rolling Process

The rolling reduction is set as 0.5 mm, the feeding rate is 490 mm/min, and the rolling speed is 2000 rpm. The radial deforming force change curve in the slab cold roll beating process, obtained in the simulation, is illustrated in the Fig. 3.

As shown in the Fig. 3, the whole process of the blank forming period is divided into the beginning stage, the steady stage and the ending stage. During the process the deforming force increases initially, then becomes steady and decreases at last. As a single beating process, the deforming force illustrates the same change tend as increasing initially and decreasing finally. Meanwhile the simulation results show

that the cold roll beating forming is a periodically loading and unloading process and the peaks and the troughs appear in a certain law.

As can be seen from the deforming force in the steady stage, the slab cold roll beating process is a periodically beating process (the beating period is 0.01 s), which indicates that cold roll beating is a process during which the blank is loaded locally, beat repeatedly and then the deformation of the blank cumulates step by step. The single beating force from the simulation is shown in the Fig. 4.

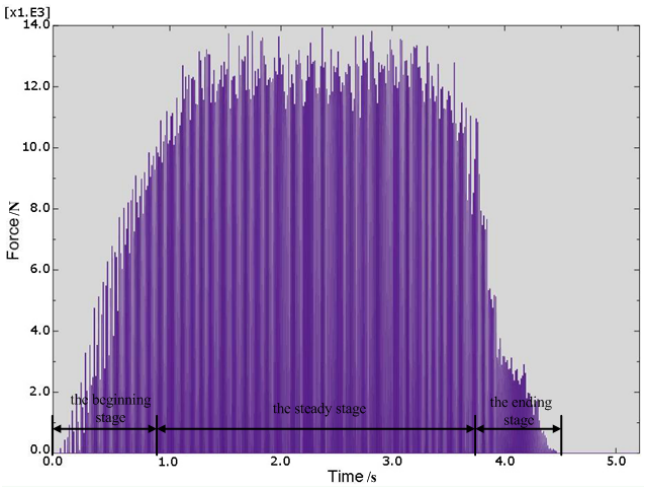


Fig. 3. Deforming force of cold roll-beating forming process.

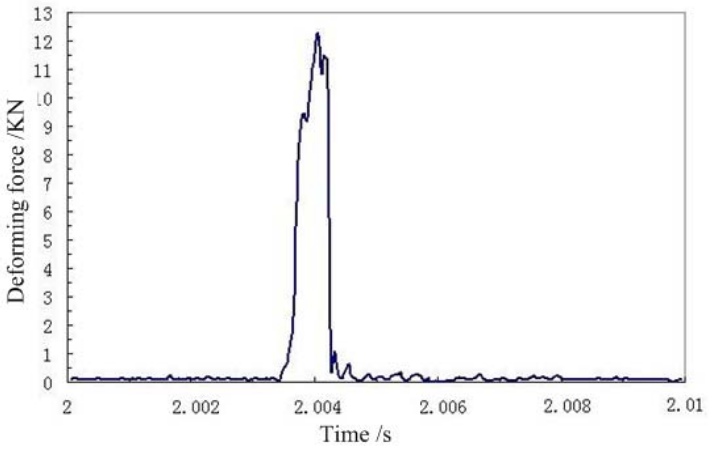


Fig. 4. Curve of forces in a cold roll-beating process.

As shown in the Fig. 4, the radial roll beating deforming force in the high-speed cold roll beating process can be generally divided into the ascent (loading) stage and the descent (unloading) stage. In the ascent initial stage the average gradient and the deforming force appear smaller. Because this is the first time that the roller and the blank contact, and the larger contact width makes the plastic deformation resistance larger, thus making the relative deformation velocity lower. In the descent stage the curve is steeper and the deformation velocity is higher. This is because the contact area is the loaded area in which area the needed deforming force is smaller than the initial force, making the deformation easier. The maximum deforming force in a single cold roll beating force process is 12.45 KN.

4.2. Influence of Rolling Reduction on Deforming Force

When the rolling reduction and the blank feeding rate are given, the single factor of the feeding depth of the roller, named as the rolling reduction, will influence the cold roll beating forming process. The rolling speed is v=1500 r/min =157.079 rad/s, and the blank feeding rate is f=490 mm/min. When the rolling reduction varies, the mean value of the maximum radial deforming force of different materials in the steady beating stage, obtained from the simulation, is shown in Table 1. And then the least square method is applied to fit the simulation value. The results are illustrated in the Fig. 5.

Table 1. Deforming force (/KN) under different rolling reduction.

Rolling reduction	0.1	0.3	0.5	0.6	0.8	1	1.2	1.5
Cu	1.075	2.26	3.502	3.59	4.33	4.87	5.41	5.55
45# steel	4.1	8.615	12.45	13.6	15.25	16.5	17.355	20

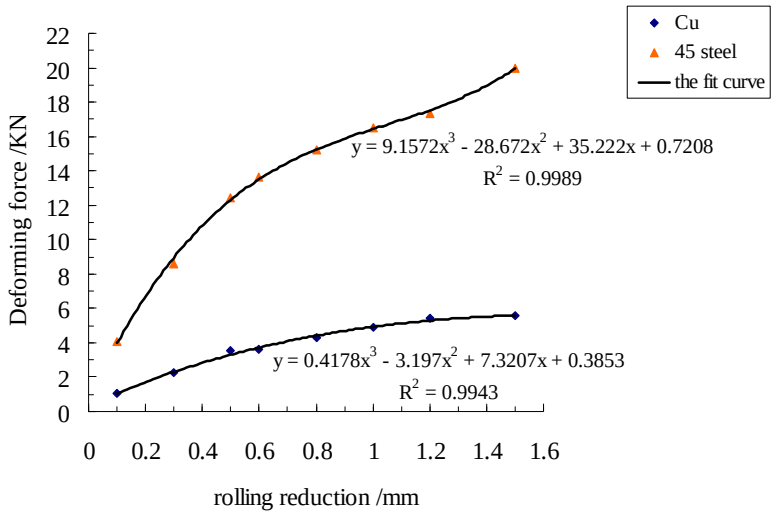


Fig. 5. Deforming force under different rolling reduction.

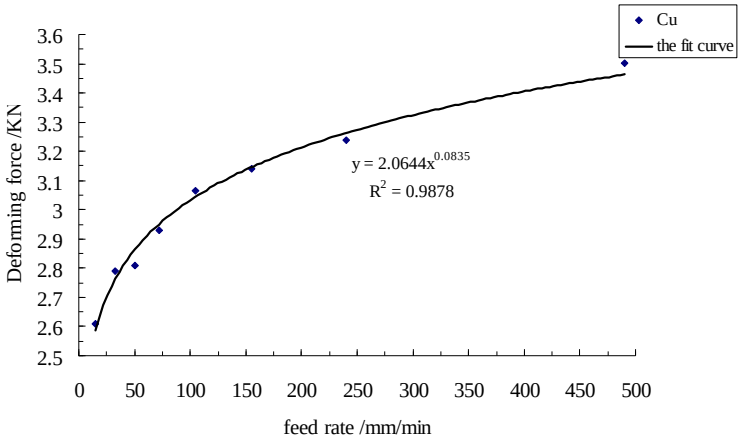
As can be seen from the Fig. 5, different reductions will have a great impact on the deforming force in the forming process. As the reduction increases, the deforming force increases gradually. While the contact area between the roller and the blank is larger, the more metal material produces great deformation in a short time. And the material relatively flows more difficult, thus leading to the deforming force increase. The smaller reduction makes the smaller deformation of the material. The time of the material flow is relatively more abundant and the deformation is well-distributed. Thus the material deformation has a smaller impact on the product performance. The forming quality of the blank, especially the appearance quality, is better.

4.3. Influence of Feed Rate on Deforming Force

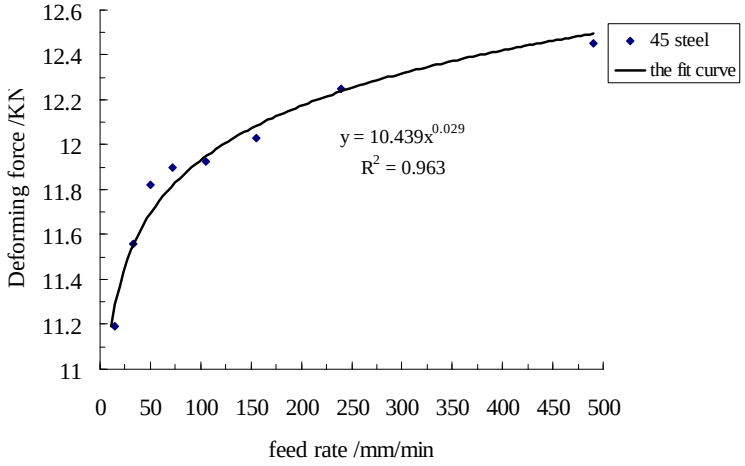
When the rolling speed and the rolling reduction are given, the single factor of the blank feeding rate will influence the cold roll beating forming process. The rolling reduction is h=0.5 mm, and the rolling speed is v=1500 rpm. The deforming force change with the blank feeding rate of Cu, hard aluminum alloy LY12 and 45# steel are shown in Table 2. And the deforming force change curves of Cu and 45# steel are illustrated in the Fig. 6.

Table 2. Deforming force under different feed rate.

Feed rate	15	33	50	72	105	155	240	490
Cu	2.61	2.79	2.81	2.93	3.064	3.139	3.24	3.502
45#	11.19	11.56	11.79	11.86	11.925	12.03	12.25	12.45



(a)



(b)

Fig. 6. Deforming force under different feed rate.

As the feeding rate increases, the deformation increases, the resistance arising while the blank produce plastic deformation increases, and the metal flow becomes difficult, which leads to the roll beating force in the roll beating process increase. When the feeding rate is smaller, the deformation is smaller and the deformation cannot penetrate into the internal of the blank, making the metal deformation heterogeneity intensified and thus influencing the forming quality. But from the simulation result, the effect of feed rate on deforming force is relatively small, compared to the influence of rolling reduction. Therefore, in the equipment permit, large feeding can be put to use from the view of improving productivity.

4.4. Influence of Speed on Deforming Force

Rolling reduction is set as 0.5 mm and the feed rate is 490 mm/min. The values of deforming force and deforming curve of Cu duralumin alloy and 45# steel are shown in Table 3 and the Fig. 7.

Table 3. Deforming force (KN) under different speed (rpm) of Cu and 45# steel.

Speed	500	1000	2000	3000	4000	5000	6000
Cu	3.56	3.531	3.62	3.87	3.774	3.57	3.52
Speed	1000	1500	2000	2400	2500	3000	4000
45#	11.93	12.45	12.48	11.73	11.59	11.455	11.38

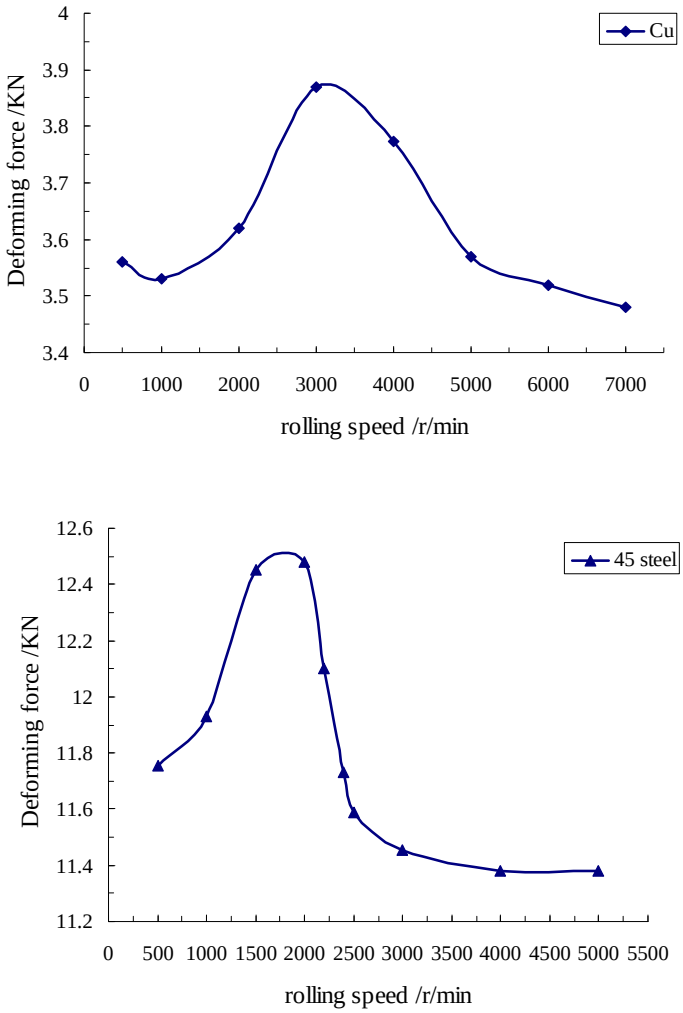


Fig. 7. Deforming force under different speed.

As is shown in the Fig. 7, deforming force increases at the beginning, then decreases with the rise of the rolling speed. At the stage of increasing, deforming force gets bigger and bigger due to significant impact of rollers. With the increasing of the rolling speed, deformation velocity increases, which results in the increase of the deformation resistance and the deforming force. Meanwhile, feed per tooth of the roller and the flow of metal decrease, which results in the decrease of the deforming force.

As the rolling speed varies, the roll beating deforming force curves of the two materials have a cusp at the relevant rolling speed. The loading process of the slab cold roll beating forming movement is transient and dynamic process. As the rolling speed increase, the dynamic impact effect plays a dominant role. At the cusp the loading frequency is close to its own frequency, which makes its amplitude reach the maximum, thus the roll beating deforming force appears the maximum.

5. Experimental Analysis

In order to verify the reliability and accuracy of the finite element simulation, the paper taking copper for test materials, cold roll-beating is carried out based on the two experiment parameters (rolling reduction, feed rate and rolling speed). The comparative analysis of the finite element simulation and the measured values is made.

The cold roll-beating forming experiments are carried out with self developed cold roll-beating equipment. As is shown in the Fig. 8, measuring system of deforming force consists of special strain dynamometer and NEC data logger RA1200.

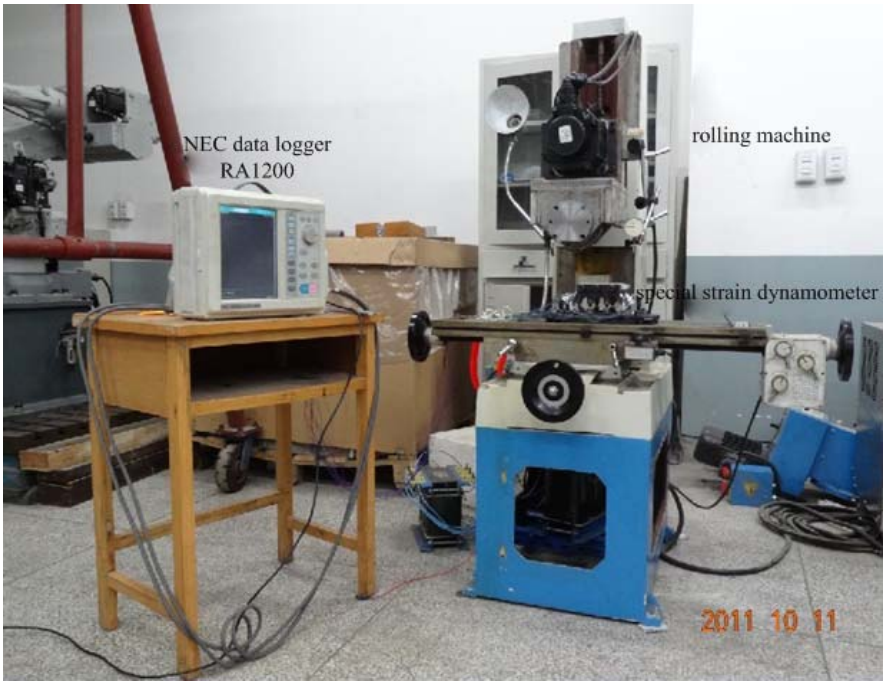
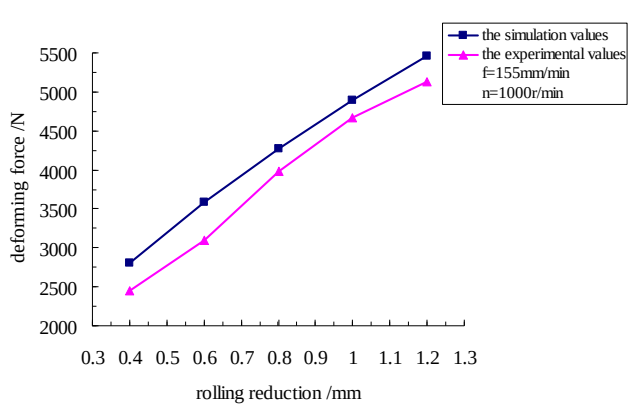


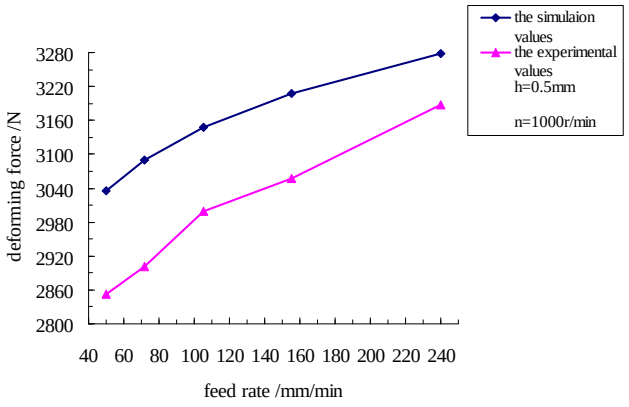
Fig. 8. Test equipment of cold roll-beating.

Sampling frequency is set as 5000Hz in measurement process, Parameters such as rolling reduction, feed rate and rolling speed are corresponding to the values of finite element simulation. Taken the peak average of the radial deforming force at the stage of stable cold roll-beating forming as the measured values, comparison curves between the simulation and the measured values are shown in the Fig. 9.

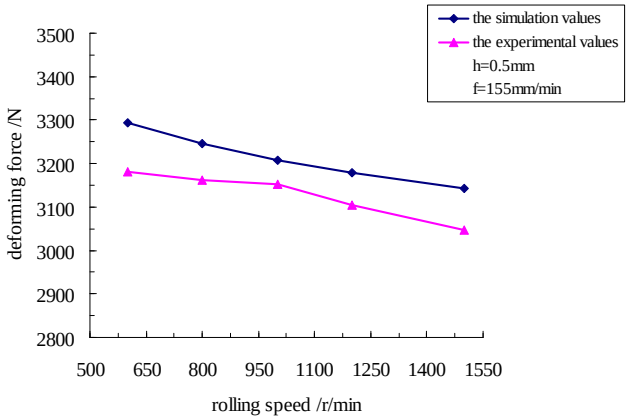
As is shown in the Fig. 9, the simulation curves based on the two parameters agree well with the experiment. Maximum deviation is about 10 %, which shows the rationality and validity of the finite element simulation. rolling reduction, feed rate and rolling speed.



(a) Different rolling reduction.



(b) Different feeding speed.



(c) Different speed.

Fig. 9. Comparison between simulation and experiment.

6. Conclusion

FEM of cold roll-beating forming is established with ABAQUS, and the simulation is completed combined with the actual processing. The deforming force of the work-piece in forming process and the effects of process parameters (rolling reduction, feed rate and rolling speed) on the deforming force are analyzed. The forming experiments are carried out with self developed cold roll-beating equipment. The validity of the finite element simulation is verified through the comparisons with the experimental data, which show good agreements with numerical simulation results. The research results laid theoretical and applied foundation for further study on the technique of single point dieless accumulation forming and high-speed cold roll-beating of function surface such as screw, gear and spline.

Acknowledgements

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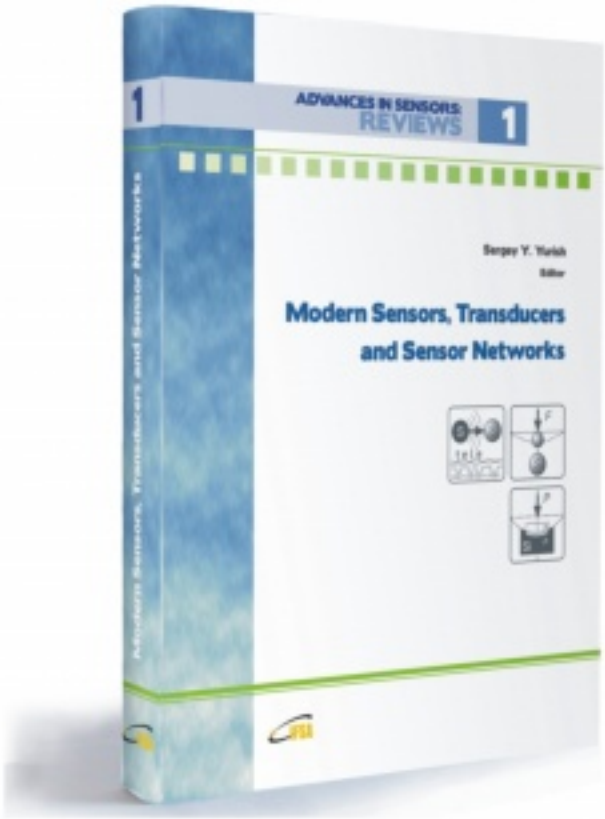

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