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Research Paper

Lateral Compression Process of Bimetallic Rods between Flat and V-shaped Dies: Experimental Analysis and Numerical Simulation

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Abstract

This study deals with the experimental and numerical investigation of the lateral compression process of bimetallic rods between flat and V-shaped dies. The bimetallic rods are long and have a round cross-section and are made of a combination of 1050 series aluminum metal as a shell and Cu-ETP R250 copper metal as a core. To determine the stress behavior in terms of the strain of these two materials, tensile test samples were made with standard dimensions, and by performing a simple tensile test, the true stress curve was drawn in terms of the true strain. To make bimetallic rods, aluminum rods and copper tubes with equal lengths were made separately. Then, the copper tube is heated in oil, and the aluminum rod is assembled inside the copper tube by applying force. The bimetallic rod is placed horizontally on the lower V-shaped die, which is fixed, and is subjected to plastic deformation by the upper flat die, which is connected to the moving part of the press machine at ambient temperature by applying compressive force. The lateral compression process was simulated by the finite element method using ABAQUS software. The geometric dimensions of the deformed bimetallic rod cross-section and the experimental forming force have been compared with the FE simulation results. The comparisons showed good agreement between the experimental and FE simulation results.

Keywords

Lateral Compression, Bimetallic Rod, Forming Force, Experiment, FE Simulation

1. Introduction

Papers Composite rods consist of two or more different materials, which are used in various industries due to their properties such as electrical conductivity, corrosion resistance, wear resistance, and high strength. For example, a rod composed of aluminum and copper metals is widely used in the electrical industry due to its electrical conductivity, lightweight, and low price [1-3]. In bimetallic rods, the desirable properties of two metals are used in one rod. A type of these rods is composed of aluminum metal as the core and copper material as the shell, which is used in the transmission of electric current.

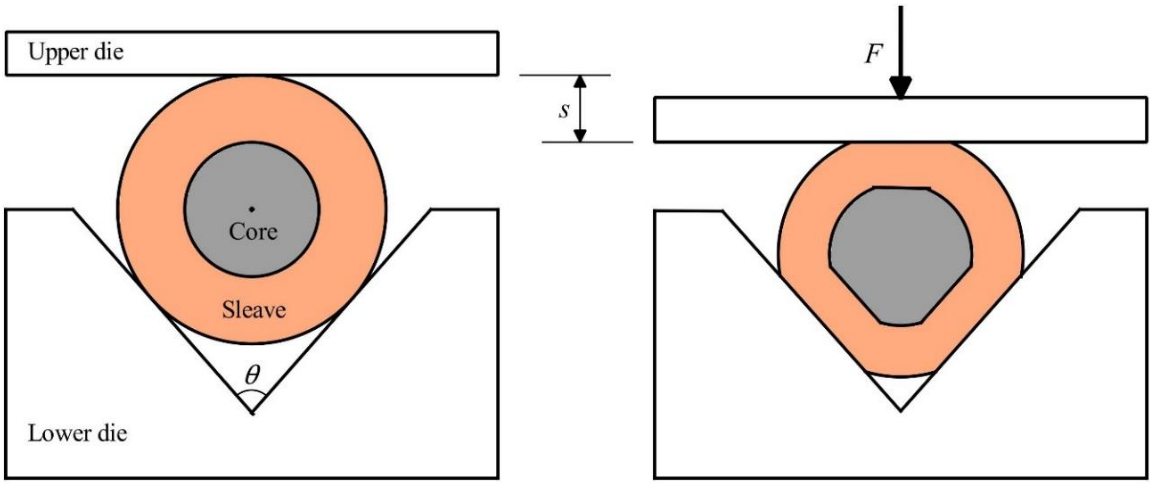
These wires are better in terms of economy and mechanical properties than single metal wires made of copper or aluminum. Due to the difference in the yield stress of the two materials, investigating the deformation of the composite rod is more complicated than that of the monometallic rod. The plastic deformation of a rod composed of two or more metals in forming processes such as extrusion and stretching has been investigated by various researchers [4-8]. The compression process of monometallic and bimetallic billets has also been investigated by many researchers using analytical, experimental, and numerical methods. Dudra and Im [9] studied experimentally and numerically the stress distribution in the open die forging process of round and rectangular billets. Based on the simulation results using billets with different dimensions and dies with different shapes, they showed that in the V-shaped die, the most stress and strain occur in the center of the billet. Kristiansen et al. [10] studied numerically the process of axial compression of column-shaped billets between flat dies and V-shaped dies with an internal angle of 90 degrees. The studied billet had a small hole in the center. They concluded that if the upper and lower dies are flat, a hydrostatic tensile stress is generated in the center of the billet and causes the hole size to increase, while if the upper die is flat and the lower die is V-shaped, it can prevent from creating tensile stress and thus preventing the growth of the hole size in the center of the billet. Ayer et al. [11] investigated experimentally and numerically the process of axial compression of bimetallic discs between flat dies and compared the results of experimental tests with process simulation in DEFORM software. They concluded that most deformation occurs in the core of the disk, and the results of the experimental test are in good agreement with the simulation results. Asa et al. [12] studied the forging process of a bimetallic billet by experimental and numerical simulation methods. In this research, the axis of the billet coincided with the direction of the forming force. Jin et al. [13] studied the formation of a bimetallic tube using a spinning process. A forming analysis of the clad tube and base tube in a spinning process was conducted through numerical simulations and experiments. They proposed a method for controlling the wall thickness of the clad tube and the base tube. Rajhi et al. [14] presented a novel experimental and computational methodology to characterize the fracture behavior of the intermetallic bonding layer particularly for the bimetallic forming applications. The proposed methodology was applied to Al-Sn bearing alloy/mild steel bimetallic composite. Parvizi Bina and Haghighat [15] analyzed the plane strain compression process of a monometallic rod of circular cross-section between flat tools using the upper bound method and the force balance method and compared the results with the numerical simulation of the process using DEFORM software. They concluded that the amount of force obtained from the force balance method is less than the amount of force calculated in the simulation and also the amount of force obtained from the upper bound method is more than the force calculated in the simulation method. Maleki and Haghighat [16] analyzed the process of lateral compression of single metal rods between flat and V-shaped dies using the balance of forces method and compared the results with numerical simulation of the process with DEFORM software. They concluded that by increasing the billet radius, the forming force will increase. Qian et al. [17] proposed a novel and effective method to fabricate the bimetallic tube using a KOBO extrusion technique with an oscillating die. Compared with traditional extrusion, KOBO extrusion enabled to induce of high-frequency deformation path changes under the combined action of extrusion force and torsion torque. The results showed that KOBO extrusion had obvious advantages in reducing the extrusion load, narrowing the deformation zone, and simultaneously increasing the forming temperature. Kazemi and Haghighat [18] investigated the process of local lateral compression of aluminum tubes by experimental and numerical simulation methods.

Tang [19] studied the hydraulic forming mechanism of bimetal pipes. The stress and strain relation between the liner and base pipe during the gradual increase in hydraulic pressure was analyzed, and the range of selected internal pressure required for bimetal pipe formation and the relation between residual contact pressure and internal pressure for the liner–base pipe interface was obtained. The accuracy of analytical predictions was verified through numerical simulation and bimetal pipe-forming experiments.

As stated, in the published articles, either the monometallic rod is subjected to lateral compression or the bimetallic billet is subjected to axial deformation. To the best of the authors' knowledge, the behavior of bimetallic bars in the lateral compression process has not been studied so far. In this article, the long bimetallic rod is placed horizontally on the lower V-shaped die and is deformed under the compressive force applied by the upper flat die. The geometrical dimensions of the cross-section after the process in three different press courses and the experimental forming force have been compared with the process simulation results using ABAQUS software.

2. The bimetallic rod plane strain compression process

The schematic of the lateral pressing process of a bimetallic rod, composed of a core and a shell of different materials, between a flat upper die and a V-shaped lower die with an internal angle θ, is shown in Figure 1. Due to the large length of the rod compared to its diameter, the process can be assumed as a plane strain process, and therefore, only the cross-section of the bimetallic rod is shown in this Figure. In this process, the lower V-shaped die is fixed, and the upper die is movable. Figure 1(a) shows the schematic of the process at the beginning, and Figure 1(b) shows the schematic of the process after the movement of the upper die equal to s. In this Figure, F is the forming force after the movement of the upper die by s, the stroke of the press.



(a) (b)

Figure 1. The process of the plane strain compression of the bimetallic rod between the flat and V-shaped dies : a) before deforming, b) after deforming

3. Simple tensile test

The simple tensile test is the simplest and most basic type of mechanical test that can be performed on a standard sample of a given material. This test usually continues until the failure of the sample and its transformation into two parts. The output of the simple tensile test is the graph of the tensile force according to the increase in the length of the sample. Then the stress change curve is obtained in terms of material strain. The metals studied in this article are aluminum 1050 series and copper Cu-ETP R250. Considering that the sample of the bimetallic rod under investigation consists of an aluminum core and a copper shell, standard samples of copper and aluminum materials were made, and tensile tests were performed with a 15-ton tensile test machine. The test is conducted at a temperature of 24 °C (room temperature), and the simple tensile test device gives the results in the form of force data in terms of displacement. The force-displacement graphs taken are transformed into true stress-versus-strain diagrams.

(a)

(b)

Figure 2. a) Aluminum specimen, b) copper specimen with standard dimensions for tensile testing

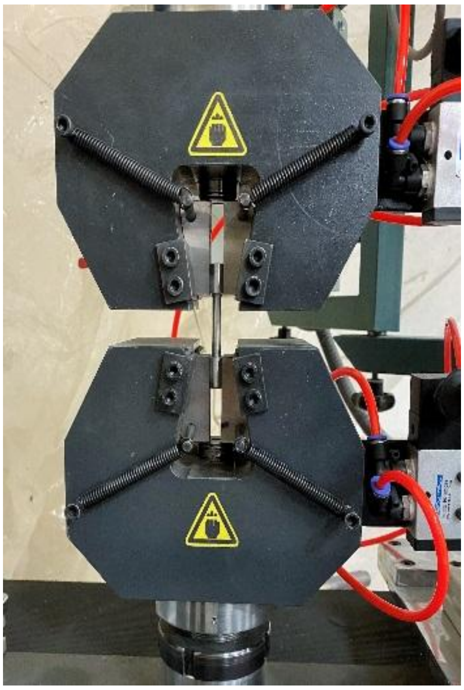


Figure 3. Aluminum specimen in the tensile test machine

Figure 4 shows the true stress-strain diagram of 1050 series aluminum and Cu-ETP R250 copper.

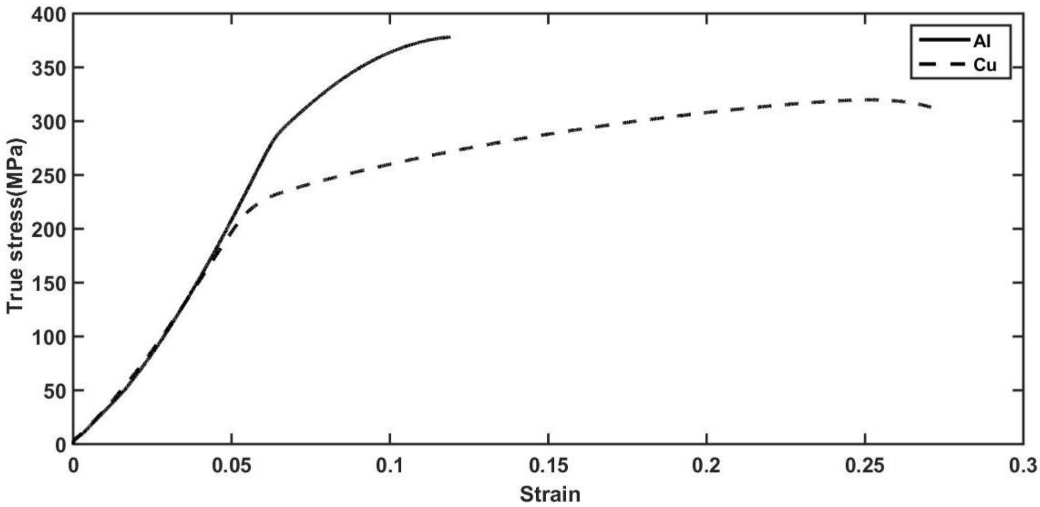
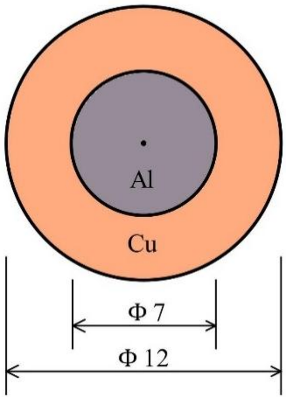


Figure 4. True stress-strain diagram of aluminum series 10 50 and copper Cu-ETP R250

4. The materials and methods

Practical lateral compression tests have been carried out on bimetallic rods made of 1050 series aluminum materials as core and Cu-ETP R250 copper material as shell. The length of the bimetallic rods used in the experimental tests is 70 mm, and their cross-sectional dimensions are shown in Figure 5 (a). To make the bimetallic rod, first, the aluminum rod and copper tube with equal lengths of 70 mm and with the cross-sectional area shown in Figure 5 (a) were made separately. Then the copper tube was heated inside the oil to a temperature of about 110 °C, and in the final stage, the aluminum rod was inserted inside the copper tube by applying axial compressive force according to Figure 5 (b). Similar to this bimetallic rod, three samples were made.



(a)

(b)

Figure 5. a) Dimensions of cross-section b) bimetallic rod sample

The upper jaw of the tensile testing machine was used as the upper flat die, and the lower V-shaped die with an internal angle of 90 degrees was made of tool steel. Figure 6 shows the upper flat and lower V-shaped dies and the bimetallic rod at the start of the process, which is installed on the press machine.

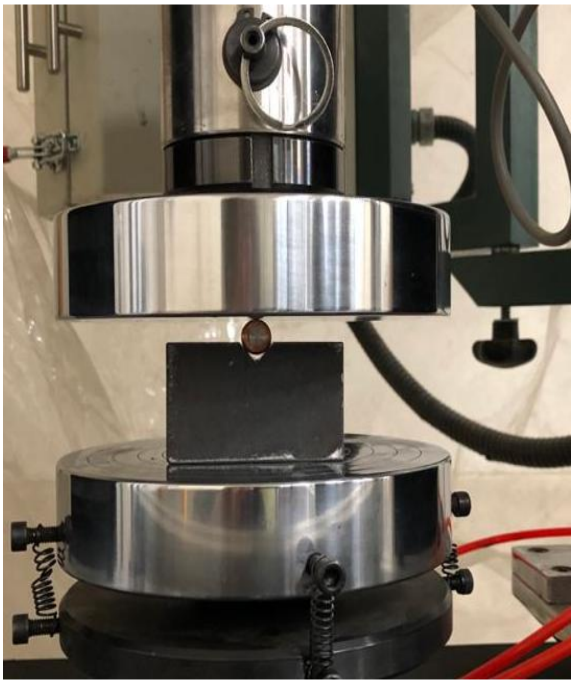
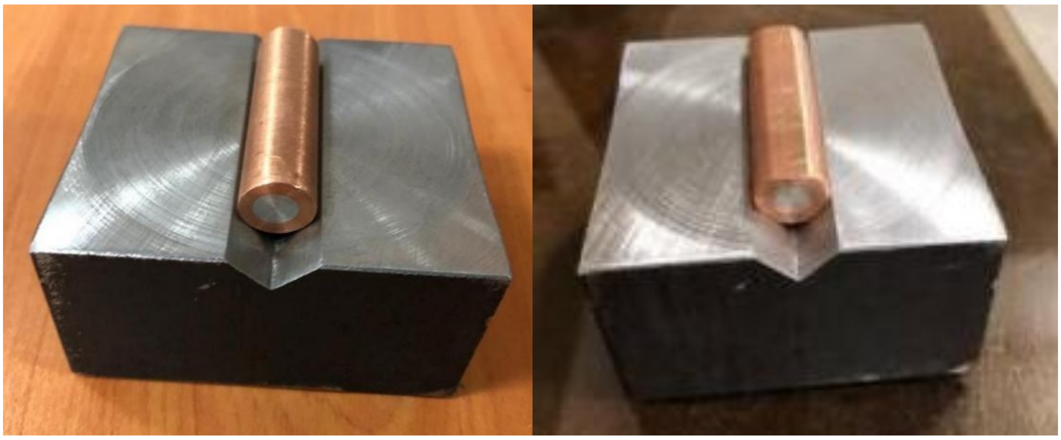


Figure 6. The process of lateral compression of the bimetallic rod at the start

After slowly moving the upper die to the given stroke and removing the force, the deformed bimetallic rod was removed from the lower die. The test was done for 1, 2, and 2.7 mm press strokes. Figure 7 shows the deformed rod along with the lower die after the press stroke equal to 2.7 mm.



(a) (b)

Figure 7. Placing the bimetallic rod on the lower V-shaped die, a) before b) after applying the compression force

5. FE simulation

Due to the geometrical symmetry, loading, and materials, symmetry is used to reduce the simulation time. The deformation process under study is a quasi-static process. There are different solvers in the ABAQUS software. Quasi-static problems are solved with both static and dynamic solvers. In the simulation of this shaping process, due to the presence of large deformations, an explicit dynamic solver is used, in which the deformation process is solved quasi-statically. Due to the length of the bimetallic rod under investigation, the simulations were modeled as two-dimensional and in the plane strain condition. The connection points between the points located on the common boundary between the core and the shell are welded together and therefore all the degrees of freedom on the boundary between the core and the shell are bound together and between the external surface of the rod and the die, the contact is defined as a surface-to-surface type. The coefficient of friction between the external surfaces of the shell and the die was considered to be 0.11. The lower die is fixed, and all its degrees of freedom are constrained. The number of 1012 quadrilateral elements is defined, and the average size of the sides of the elements is 0.2 mm. By increasing the number of elements, there was no change in the simulation results, and only the simulation time increased. Figure 8 (a) shows the FE simulation model of the rod cross-section at the beginning of the process, and Figure 8 (b) shows the deformed model of the bimetal cross-section in the press stroke of 2.7 mm.

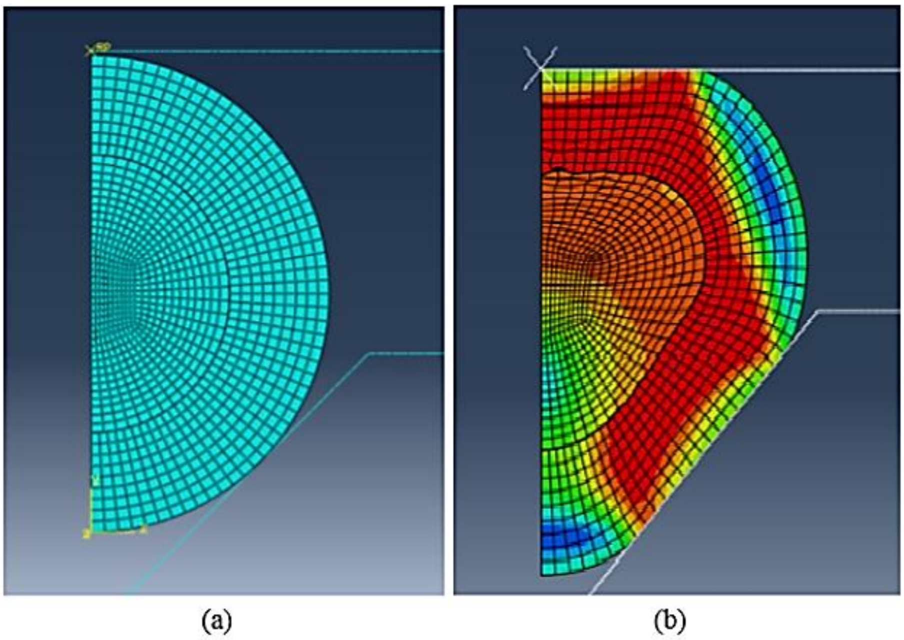


Figure 8. a) FE simulation model, b) deformed mesh after the implementation of the process at press stroke 2.7 mm

6. Results and discussion

The contact lengths of the bimetallic rod with the die surfaces in a certain stroke of a press machine are shown in Figure 9. These dimensions are measured from the cross-section of the rod output from the test in three press courses equal to 1 mm, 2 mm, and 2.7 mm, and compared with the process simulation results.

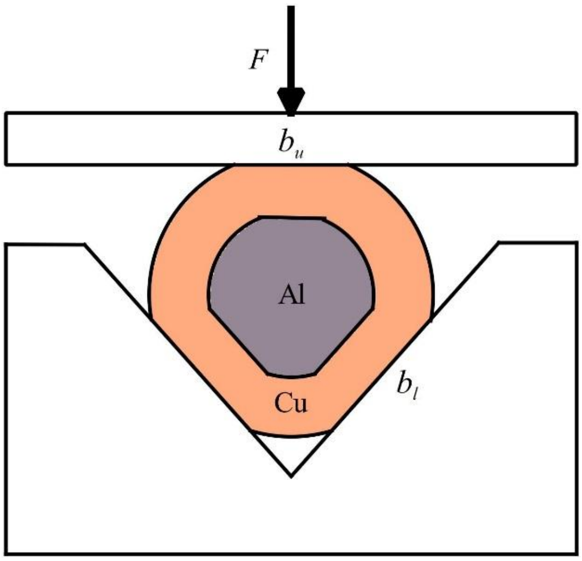


Figure 9. The contact lengths of the bimetallic rod with the die surfaces

The results of simulation and experimental tests of the contact lengths of the deformed rod cross-section with the upper and lower dies, in press stroke 2.7 mm, were compared (Table 1). According to this table, the experimental results of the contact length are smaller than the simulation results. With the increase in the press stroke, the difference between the practical test results and simulation data has increased.

Table 1. Dimensions of contact lengths of the rod, with the surfaces of the upper and lower dies

Stroke, mm	b_u Experiment	b_u Simulation	b_l Experiment	b_l Simulation
1	2.1	1.9	2.4	2.1
2	2.7	2.2	2.9	2.4
2.7	4.1	3.7	4.6	3.9

The graph of the change in the forming force according to the press stroke taken from the experimental test and numerical simulation data is shown in Figure 10. As expected, with the increase in the press stroke, the forming force increases. This is because, with the increase in the press stroke, more volume of the material is deformed, and also due to the work hardening of the rod materials, the forming force increases. Also, with the increase in the press stroke, the friction surfaces become larger, and to continue the deformation, the forming force increases. Up to the press stroke of 1.2 mm, the force curve obtained from the finite element simulation is higher, and after that, it is lower.

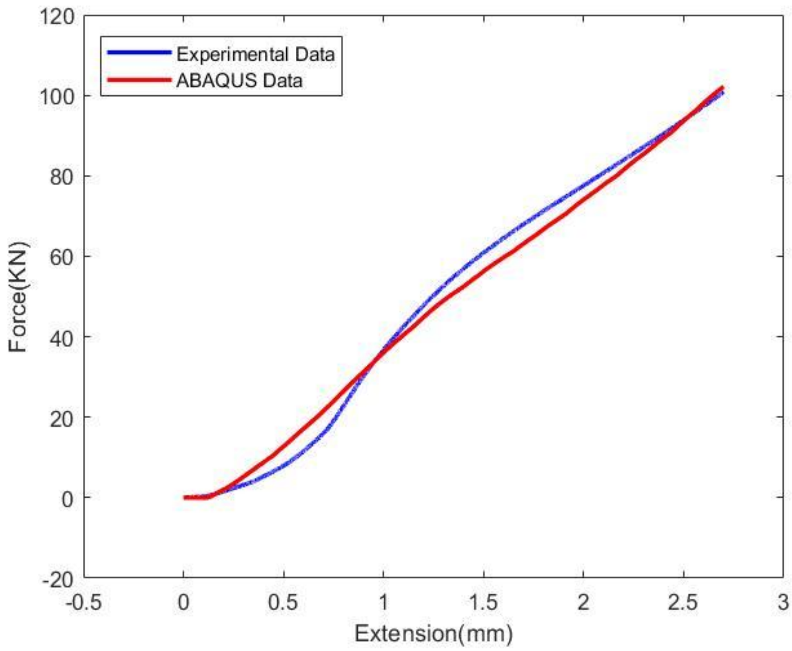


Figure 10. Experimental and numerical diagrams of the change in the forming force according to the press stroke

7. Conclusions

In this article, the lateral compression process of bimetallic rods between the upper flat and lower V-shaped dies was investigated by both experimental and numerical simulation methods. The geometric shape of the cross-section and the experimental data of the forming force were compared with the FE simulation results using ABAQUS software, and the following results were obtained:

- By increasing the press stroke, the forming force increases.
- The geometrical dimensions of the deformed bimetal rod cross-section are in good agreement with the FE simulation results.

- The results of the experimental work and numerical simulation of forming forces are close to each other.

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