Finite Element Simulation of Hydrostatic Extrusion Process to Produce Thin Bimetallic Parts

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Abstract
The hydrostatic extrusion is a new method of extrusion process. The most important advantage of this method is reduction of friction and close tolerance for the coating thickness. In this study, the hydrostatic extrusion simulation of bimetallic wires has performed using of finite element method. In the following the advantages of hydrostatic extrusion compared to the direct extrusion are presented.It can be concluded that by increasing the friction coefficient between the work piece and the die, the extrusion force value also increases. Increasing the cross-section reduction when the die angle kept constant as a result of increase in die length, consequently leads to an increase in the extrusion force.Regarding to the absence of friction in the die and almost uniformly deformation and homogeneous in the hydrostatic extrusion, the product with a uniform coating thickness can be obtained as it is very important for manufacture of very high length bi-metal products.

Keywords
Hydrostatic Extrusion, Bimetallic Wire, Finite Element Method

1. Introduction

Bimetallic wires are a type of wires, which apply simultaneous properties of two (Or sometimes multiple) metals to improve the properties. It makes wire production process beneficial for in the industry. The aluminum wires with the copper coating have an aluminum core with solid layer of copper that is mixed as a metallic bond with aluminum. The copper coating thickness is various in different cables and is often 10% by volume or 40% by weight of the cable. The aluminum with copper coating is obviously distinct able from copper and aluminum cables. It is lighter than copper an easier to apply. It is more affordable and has lower transport costs. At the same time, the copper / aluminum connectivity is as easy as connection between two copper parts and no specific connection or combination joint is required for aluminum with copper coating. On the other hand, the aluminum wire ductility with copper coating is equal to aluminum wire ductility and it has higher electrical conductivity. The aluminum wire with copper coating as the central conductivity in the coaxial cable for the television central antenna has been practically replaced by copper single wire cable. The less wire weight provides the possibility of applying insulation materials with lower-density to achieve better attenuation and then the impedance discontinuities and capacitor decrease, as the aluminum wire with copper coating needs half of the necessary force to bend the copper wire [1].For the success of cladding with extrusion, it is necessary that the flow stress of two metals be the same. Two main objectives of the claddings process with the extrusion are as follow:

A) Create a complete and perfect connection between two metals;

B) The ratio of the coating thickness to the intermediate metal must be fixed throughout the coated product.

To realize two above mentioned objectives, a stable extrusion conditions (having the fixed deformation temperature and the same flow form) should be established. According to a hydrostatic extrusion method, desired cladding conditions can be provided.

In this method, the material inside the extrusion die, rather than the pressure resulted from press piston (ram), moves forward due to the pressure of a fluid and then passes through the die. There is a layer of lubricant material around the rod and some of the pressurizer fluid inside the die cavity. The pressurizer fluid amount should be so that the necessary hydrostatic pressure can be created with the movement of piston which has equipped in the front with a sealing ring. The lubricant material applied on rod before beginning of the process is different from pressurizer fluid. This lubricant material may include wax, grease oil lubricant or a highly concentrated lubricant fluid. Before entering the rod into mold, this material can be rubbed over the rod and therefore its value is very low. If the lubricant material is too thick, the phenomenon of stick-slip effect may be occurs and the product appearance changes into bamboo rings. If the lubricant material is too thin, this lubricant material layer will be completely destroyed and broken. To implement this process, it is necessary to overcome the problem of sealing fluid under pressure. This method can be done in both forms of cold and hot. To implement this process, an aluminum rod should be embedded into a copper tube and used as a composite rod.The absence of friction in the mold cavity and almost uniform and homogeneous deformation cause that the obtained product with coating has a uniform thickness with high length [2].Many studies have been conducted to develop metal extrusion process. Hartley [3] analyzed using of upper bound method for the pipe extrusion process that consists of three metal layers, in which the inner and outer layers material was the same. He also investigated the effects of friction constant parameters, the mold half-angle, the ratio of extrusion, and the mandrel radius on the extrusion partial pressure. Yang and Han [4] analyzed the deformation area for the extrusion process of two metal rods with a curve form and used the finite element method. They found that the extrusion pressure in stationary conditions has direct relationship with the border function, and also the axial flow in the center of the beam is relatively faster for larger constant friction with the same mold form, compared to the outer body of the mold. Using upper bound method and experiment, Tokuno [5] analyzed deformation in extrusion of composite rods and single metal and besides investigating the effects of core and work piece hardness, he examined the effects of mold half-angle parameters, constant friction and the reduction percentage in cross-section area. At first, they considered a hard core and a soft work piece and compared it with the reverse mode. They concluded that the shape of geometric border will not be so much different in both cases, but the required extrusion force for bimetallic rod is greater when the core is soft. Hwang et al. [6] investigated the extrusion plastic deformation behavior of the composite rods in the form of a cone shaped in terms of the upper bound method. They performed an experiment and examined the effect of friction constant, the mold half-angle, and reduction percentage in cross-section over the extrusion force. The ratio of core radius to product work piece using upper bound method was evaluated as well. Saniei [7] which had examined the composite rod direct extrusion of lead and tin using practical experiments and finite element analysis, indicated that by increasing the molding angle, extrusion force increases. On the other hand, the effect of the mentioned parameters on the ratio of the product cross-section is not significant, but in the experimental results in the large billet surface proportions and especially when the work piece is harder than the core, it has little influenced. Khosravi Fard et al. [8] studied the parameters affecting the strength of Al-Cu bimetallic rod extrusion border by finite element software ANSYS-LS DYNA and performing an experiment. Pourglolov et al. [9] analyzed finite element of hydrostatic extrusion process for aluminum metal. Analytical and numerical solution of hydrostatic extrusion process was studied at different pressures. The amount of stress was studied for the triple points of extrusion as well as for the direction of metal flow. It was observed that the stress in the work piece increases with the beginning of process and then takes a roughly steady trend. Lee et al. [10] also examined the impact thickness of inter metallic compound, IMC, which is created under the effect of the hydrostatic extrusion process for Al / Cu bimetallic wire.They found that thermal conductivity of Al / Cu bimetallic wire influenced the IMC thickness and thermal conductivity decreased by increasing the IMC thickness. Moreover, examining mechanical properties of bimetallic wire suggested that the maximum tensile strength increases and increase in tensile strength leads to increase in bimetallic wire strength.

The above literature review proves that insufficient studies exist on the bi-axial thin wires. The conducted empirical work in this paper for bimetallic wire is related to a regular hexagonal matrix, while industry has greater demands on round shape bimetallic wire. Therefore, to fix this deficiency, the simulation process has been intended with Abaqus finite element 6-14-2 software based on bimetallic wire with a round shape matrix with the identical output dimension. Regarding independence of the responses from mesh network and verification of the results, this process was investigated in several stages and with change in elements sizes and dependent parameters. To perform simulation verification in the first step the bimetallic direct extrusion simulation accordance with mentioned report in ref. [6] was also performed and was compared with experimental work. In the second step, process simulation has been done for hydrostatic condition. The effective parameters (Extrusion force, dieangle, friction, etc.) have been investigated to consider this process. The practical aim of this work is to investigate different states of material flow, extrusion force prediction to obtain the bimetallic wires using hydrostatic extrusion.

2. Materials and Methods

2.1 Materials

The geometry of billet used in this study, in fact, was the same as billet used in article [10]. The core is made of aluminum material and the work piece is made of copper material. The aluminum core is a rod with a length of 237 mm and a radius of 27 mm and the copper work piece is a tube with a length of 237 mm and a radius of 30 mm. The mold half-angle is 25 degrees, so that the core radius ratio to total the input rod is 0.9. [10], [11].The die cavity was filled with a fluid and the force was exerted by the same fluid uniformly to the pieces. As a result, there was no contact between the work piece and the die cavity wall. The shear friction constant between the work-piece and the die was frictionless and the friction constant related to the work-piece surface and the die during the extrusion and between two metals were considered $\mu_1=0.1$ and $\mu_2=0.9$, respectively [9]. The mechanical properties of aluminum and copper can be expressed by the following equations as mentioned in [6].

$$\sigma_{Al} = 189.2\, \varepsilon^{0.239} \quad (1)$$

$$\sigma_{Cu} = 335.2\, \varepsilon^{0.113} \quad (2)$$

3. Finite Element Model for Extrusion Process of Bimetallic Wire

The bimetallic wire hydrostatic extrusion simulation was performed by Abaqus software. The pressure and other relevant parameters are summarized in Table 1 and Figure 1.

Table1. independent parameters for hydrostatic extrusion

Load(MPs)	1700
Temperature $°_C$	200
Mesh Size(mm)	8
Time period (S)	0.003

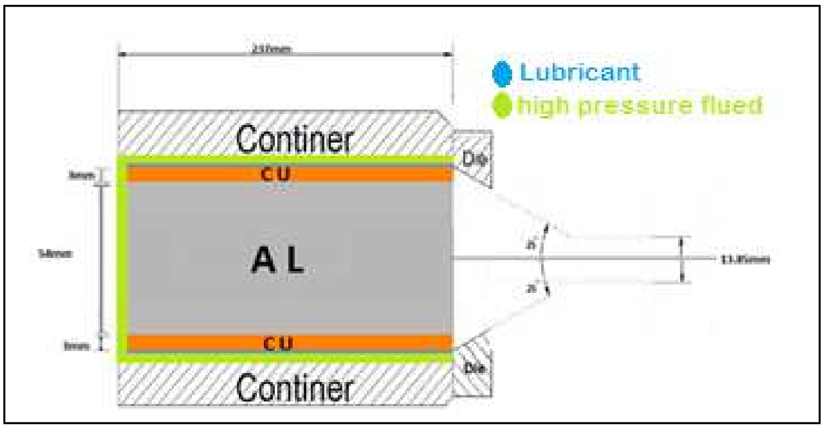

Figure1. schematic view of the hydrostatic extrusion

In the implemented model, the mold and matrix were constant and the force exerted through the fluid into the pieces and created the conditions for deformation. Due to complicated conditions of contact and large deformations, for simulating the problem a Dynamic analysis, Explicit is determined.

3.1 Geometry and Mesh

An Axisymmetric model consists of three parts which were created in Abaqus.These three parts include two deformable parts consist of a core and work piece and a rigid part as the mold. Quad shape elements and automatic meshing were selected. An Explicit and linear element, from axisymmetric Stress were selected for core and an Explicit and linear element, from Coupled Temperature-Displacement were selected for work piece. Comparison showed that the last mesh had the optimum size and obtained acceptable analysis. In order to investigate the model independency, meshes with three different sizes of 16, 8 and 4 mm were implemented. The mesh and full geometry have been shown in Figure 2.

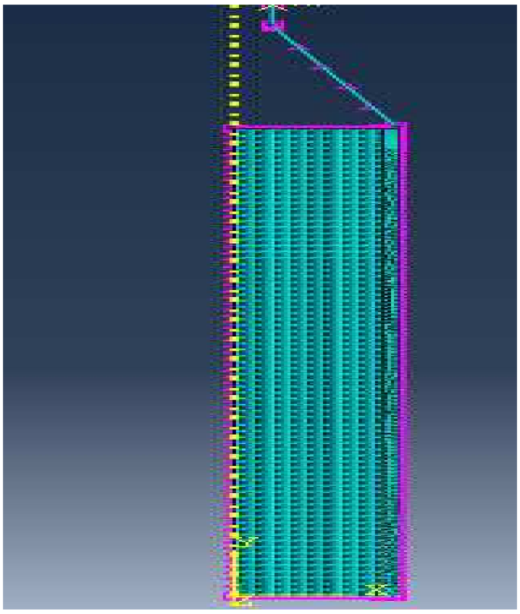

Figure2. mesh and full geometry of the hydrostatic extrusion

In this article, the lubricant effect was simulated by using define the friction coefficient between work piece and die and constant friction between two metals during extrusion, μ_1=0.1 for hydrostatic extrusion and direct extrusionμ_2=0.9 respectively.

3.2 Boundary Conditions

The boundary condition of the parts in contact with the die (Matrix) is mechanical contact type. The contact condition for work piece with environment is a constant pressure type. According to Figure 3, in order to implement process and in the direction of the required axes pressure is applied. In addition, in this simulation, the composite billet before the process performance is heated at a temperature of 200°C.

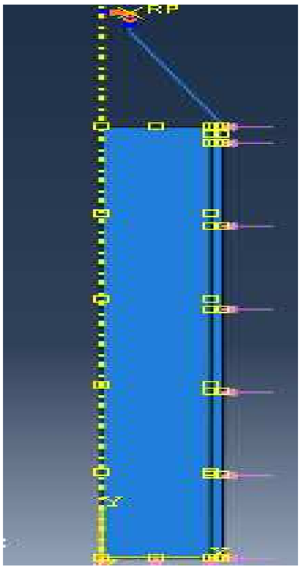

Figure3. boundary condition of implemented simulation

3.3 Extrusion Simulation (Hydrostatic and Direct)

With the implementation of the boundary condition on the composite billet, a pressure of 1700 MPs [10, 11] was applied. The friction coefficient between the work piece and die was considered 0.1 and displacement boundary condition was affected for punch. In order to apply this boundary condition, a reference point was created during the punch modeling (in the direction of die axis). The displacement of 20 mm was applied for billet. The die angle and the core radius ratio to the total input rod were 15 degrees and 0.6 respectively.

4. Discussion and Conclusion

In several steps, of the mesh size was change and the dependent parameters such as equal stress were investigated. Results reveal that the stress value in all cases has not been changed which it was concluded that the mesh size was independent from simulation results. Figure 4 shows Mises Stress during the forming process.

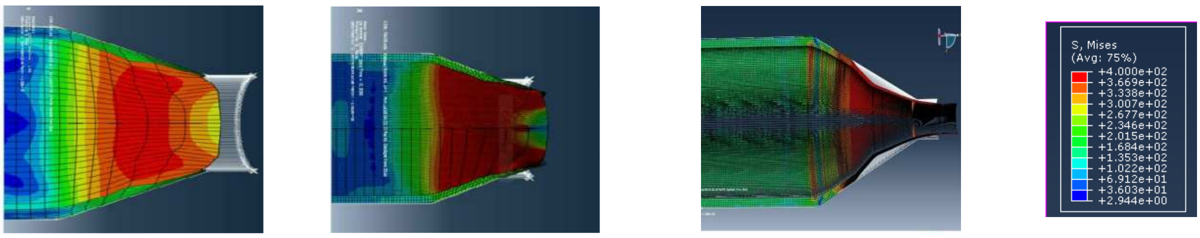

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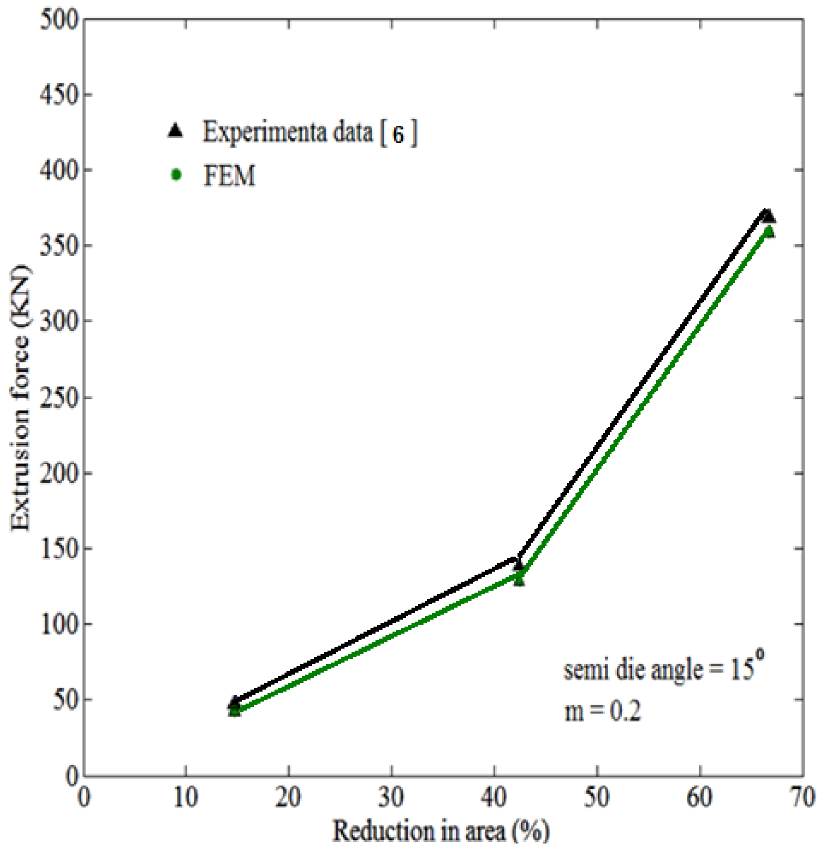
Figure4. Mises Stress during the forming process

Comparison between direct extrusion simulation results and the experimental results obtained from Reffrence [6] is shown in Figure 5. It appears that the simulation results have a good agreement with experiments.



α	15degree
m1	0.2
R1i	30mm
R2i	[7.5],[12],[15],[18],[22.5]mm
m2	0.9

sleeve	core
CU	Al
$\sigma_{Cu} = 335.2\ \varepsilon^{0.113}$	$\sigma_{Al} = 189.2\ \varepsilon^{0.239}$

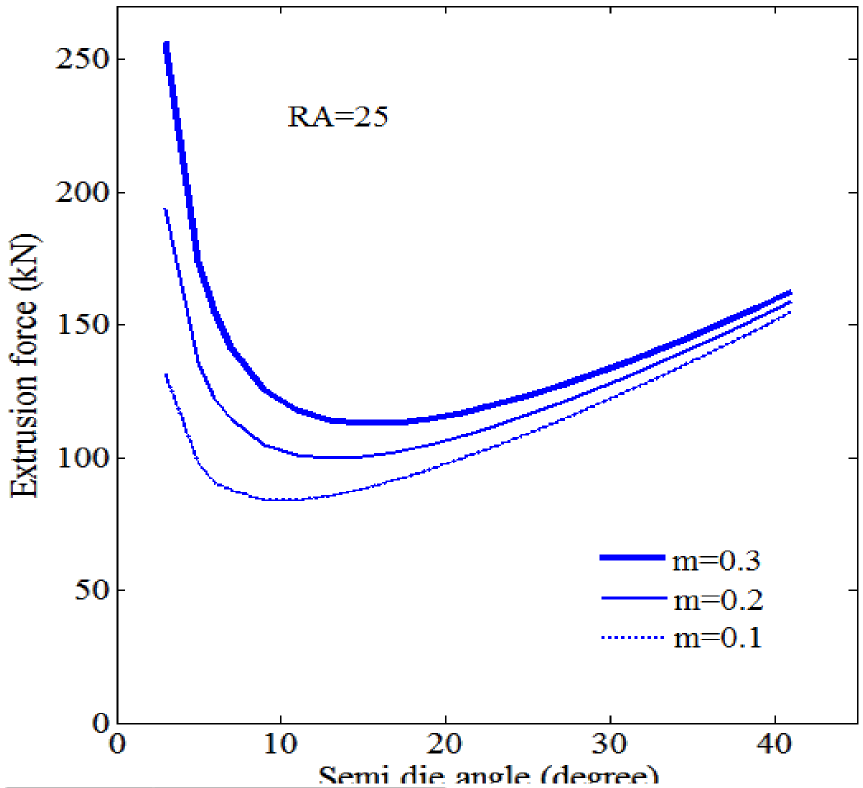
Figure5. Comparison between direct extrusion simulation forces and the experimental results obtained from [6]

4.1 Effect of the Extrusion Parameters on the Finite Element Simulation Results

In this section effect of the die angle on the extrusion force in constant cross section reduction and also the effect of the cross-section reduction in various die angle on the extrusion forces are investigated.

4.1.1 The Effect of the Die Angle on the Extrusion Force

The effect of die angle in the extrusion force in various friction coefficients between the work piece and the die is shown in Figure 6. As seen in Figure 6, by increasing the friction coefficient between the work piece and the die, the extrusion force also increases. It can also conclude that in the large die angles, the effect of friction coefficient between the work piece and mold has no effect on the extrusion force, while in the small die angles, the extrusion force decreases by increasing of the friction constant coefficient in constant cross-section reduction. The reason of above mentioned changes is that for the smaller die angles, the friction surface is higher than for the large die angle, so by increasing the friction surface in the case constant of cross-section reduction, the frictional resistance is increased and accordingly, the extrusion force increases. However, in large die angles, since the friction contact surface proportionally is low, so in the constant cross-section reduction, the extrusion force is not slightly changed.



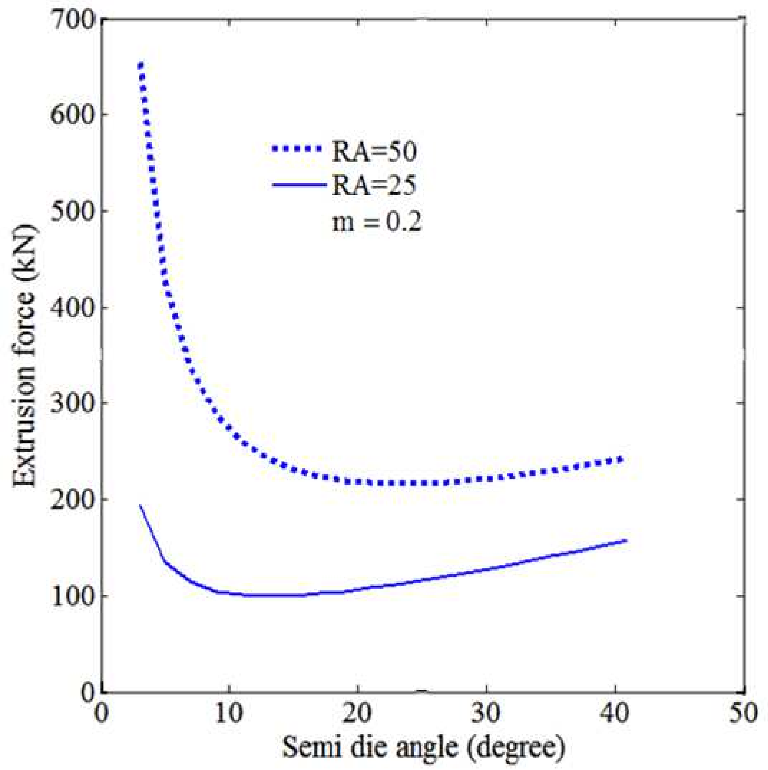
α	15degree
m1	0.2
R1i	30mm
R2i	[7.5],[12],[15],[18],[22.5]mm
m2	0.9

sleeve	core
CU	Al
$\sigma_{Cu} = 335.2\ \varepsilon^{0.113}$	$\sigma_{Al} = 189.2\ \varepsilon^{0.239}$

Figure6. effect of die angle in the extrusion force in various friction coefficients between the work piece and the die

4.1.2 Effect of the Cross-Section Reduction on the Extrusion Force in Various Die Angle

The variation curve of the extrusion force versus die angle in different cross-section reduction is shown in Figure 7.As it is observed, by increasing the cross-section reduction, the optimum value of the mold half-angle decreases. The optimum die angle is appeared to be in the lowest extrusion force. It can be also concluded that in the large die angles, the extrusion force slightly changed, while in small die angles, the extrusion force abruptly decreased. As the die angle increases, the mold contact surface length reduces, the billet pushes forward with less limitation.



α	15degree
m1	0.2
R1i	30mm
R2i	[7.5],[12],[15],[18],[22.5]mm
m2	0.9

sleeve	core
CU	Al
$\sigma_{Cu} = 335.2\ \varepsilon^{0.113}$	$\sigma_{Al} = 189.2\ \varepsilon^{0.239}$

Figure7. The extrusion force versus die angle in different cross-section reduction

5. Conclusion

The results of direct extrusion simulation for bimetallic wire had very good agreement with the experimental results. Considering the bimetallic wire hydrostatic extrusion process is simulated with several steps in terms of the elements size change and the dependent parameters change, it can be concluded that the results are independent of the mesh network and the results can be assured to be accurate. By increasing the friction coefficient between the work piece and the die, the extrusion force value also increases. Increasing the cross-section reduction when the die angle kept constant as a result of increase in die length, consequently leads to an increase in the extrusion force. The stress distribution in the hydrostatic extrusion simulation of Al/Cu bimetallic wire is more uniform than for the bimetallic Cu/Al wire. In hydrostatic extrusion process after reaching to the upper limit power, the other force does not change compared to the punch displacement, but in the direct extrusion process, it is required more force than the hydrostatic extrusion process. In hydrostatic extrusion due to lack of friction between the billet and the die, the extrusion force is considerably less than the direct extrusion. Using the hydrostatic extrusion method for soft metals, the production steps can be eliminated, on the other word the reduction percent can be increased for each steps.Regarding to the absence of friction in the die and almost uniformly deformation and homogeneous in the hydrostatic extrusion, the product with a uniform coating thickness can be obtained as it is very important for manufacture of very high length bi-metal products.

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