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Research article

A numerical simulation of accumulative press bonding process of laminated MMCs

Vahid Nayeri[1], Saeed Daneshmand[*2], Mohammad Heydari Vini[3], Mohammad Yazdaniyan[4]

[1]*Department of Mechanical Engineering, Majlesi Branch, Islamic Azad University, Isfahan, Iran*
[2]*Department of Mechanical Engineering, Isfahan (Khorasgan) Branch, Islamic Azad University, Isfahan, Iran*
[3]*Department of Mechanical Engineering, Mobarakeh Branch, Islamic Azad University, Mobarakeh, Isfahan, Iran*
[4]*Mobarakeh Steel Company, Isfahan, Iran*

[*]S.daneshmand@khuisf.ac.ir

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Abstract
Nowadays, the use of bimetallic laminates with special capabilities and features is increasing and has experienced high growth. These properties include high mechanical properties, corrosion resistance, light weight, resistance to noted good abrasion and thermal stability. In the midst of the technologies of multilayer composite materials Accumulative Press Bonding (APB) is one of the most common techniques for the production of multilayer composites. One of the most important aims for this choice is the press pressure, which can create a strong and suitable mechanical connection between Produced metal layer components. In this study, the Accumulative Press Bonding method has been used to produce aluminum and copper composites and the process modeling has been done by ABAQUS finite element analysis software. In this paper, the effect of Press parameters such as strain and number of layers on the distribution stress of forming this type of composites has been investigated. Shear stress among the layers reached to about 4MPa for samples with eight layers which is a good condition to generation a successful bonding. With increasing thickness, the stress applied on the layers has also increased. Maximum stress also increases significantly. As the thickness decreases, the interlayer shear stresses also increase. With increasing percentage of thickness decrease, the amount of sinking of the layers in each other has greater than before, which has led to the crushing of copper layers along the entire length of the sample. During the process, as the number of passes increases, the volume of virgin material in the direction of the press rises, which leads to increased compaction and better adhesion of the layers to each other.

Keywords: Metal matrix composite; Accumulative press bonding; FEM

1- Introduction

One of the most up-to-date and innovative methods of severe plastic deformation (SPD) is the Accumulative Press Bonding method (APB), in which strain accumulation leads to severe plastic and microscopic changes in materials [1,2]. In this process, for the production of metal composites, two or more different sheets are used as the base phase and the reinforcing phase, which is pressurized and the connection operation is performed using high pressure. The microstructure of the samples obtained from the process has been investigated by ABAQUS analytical software [3]. The outcomes of microstructural studies show that by increasing the number of passes of the Accumulative Press Bonding process, the distribution of the reinforcement phase within the network is improved and leads to failure and fragmentation of the reinforcement layers along the entire length of the specimen. Moreover, the final strength, hardness and length changes of the composite are increased by repeating the process so that the final strength of the composite is increased at higher passes. Also, fracture studies have shown that the type of composite failure is soft shear failure [4]. Nowadays, the use of computer simulation software to improve the performance of various systems has become very common [5,6]. Notable advantages of this method include reduced costs, reduced sample review time, the possibility of reproducibility and the ability to understand the performance of the research [7- 11]. Based on the simulation technique, the actual physical response can be predicted and estimated under various conditions, and the effect of variables can also be observed [12-16]. Usually about the accumulative press bonding process, experimental studies are prominent and no other numerical simulation has been done yet. So, in this study and for the first time, the combination of experimental investigation and numerical simulation of APB process has been conducted as its novelty for the first time [9, 10]. The main purpose of this study was to numerically simulate the Acumulative Press Bonding process of Al/Cu bimetallic composites as well as the study of mechanical properties of composites produced in Abaqus software.

2- Numerical modeling

In this research, the stress parameters and the number of composite layers have been analyzed and then the results have been verified by performing simulations by means of Abaqus software. To perform the process of Accumulative Press Bonding simulation [1], we have first drawn aluminum and copper sheets in Abaqus software environment with dimensions of 40 × 20 mm and a thickness of 1 mm and assigned the properties of each material to it (Table 1). Fig. 1 shows the experimental set up for the APB process.

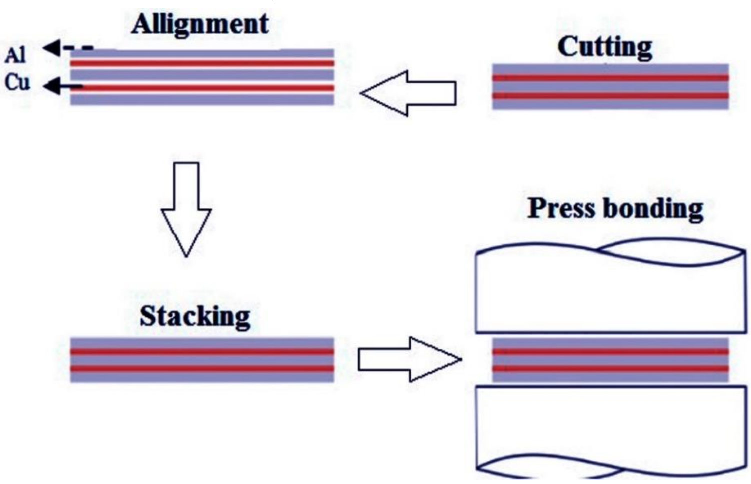

Fig. 1 Experimental set up for the APB process

Owing to the fact that the layers used in this project is made of two parts and with two different materials of copper and aluminum, hence the properties of each of them are entered separately in the relevant tables and introduced to the software. These properties include density, Young's modulus, Poisson's ratio, and material properties in the plastic deformation range. The process is performed at ambient temperature and also the Accumulative Press Bonding process is performed in three passes (two, four and eight layers).

Table 1: Properties of copper and aluminum and their plastic deformation zone

Element	Density (Kg/m^3)	Poisson's ratio	Young's modulus	Yield Stress	Plastic Strain
Al	0 to 0.83	0.31	90	0.3	2700
Cu	0 to 0.83	0.34	70	0.3	8900

In order to perform the process in different passes (two, four and eight layers), the layers are prepared in the software environment and then the control components of the process include assembling one layer of aluminum and one layer of copper on top of each other, placing the layers between the press machine molds, determining the type of process analysis, defining the contact conditions and physical properties between the layers, loading and applying boundary conditions, meshing and finally the problem solving process were applied to perform the pressing and Accumulative Press Bonding process. table 2 presents the friction coefficient during the simulation.

Table 2: Friction coefficients between components

Friction coefficient between copper and mold	0.3
Friction coefficient between aluminum and mold	0.25
Friction coefficient between copper and aluminum	0.15

Since only one of the two rigid parts of the upper mold and the lower mold acts as a bed in this process, then the mass is defined by the upper mold. Regarding the lower format, it should be noted that this format should be fixed in all directions and should not move, so in defining the boundary conditions, a suitable clause should be selected and applied for it. Determining and placing the boundary conditions for the sheets is also done in such a way that the condition of not moving up and down to the joint of the layers was added. In the next part, the modeled geometry was meshed for all stages of APB, two, four and eight layers for final analysis. Since the size and number of meshes affect the accuracy of the analysis results, the independence of the mesh was performed in this analysis and meshing was performed based on it. Fig. 2 shows that problem layers of different sizes are analyzed in meshes.

As shown in diagram 1 and mesh sensitivity analysis in Fig. 3, after several steps of resizing the mesh and reducing their size, by reducing the grain size from 0.05, the changes in the answers are very small, indicating that the mesh network is approximate in size approximately 0.05 and smaller. Therefore, to reduce the problem solving time, the largest mesh size for which the appropriate answer is obtained is considered.

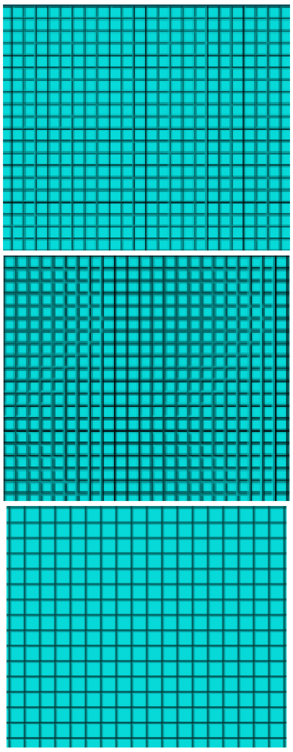

Fig. 2 Meshing with different sizes

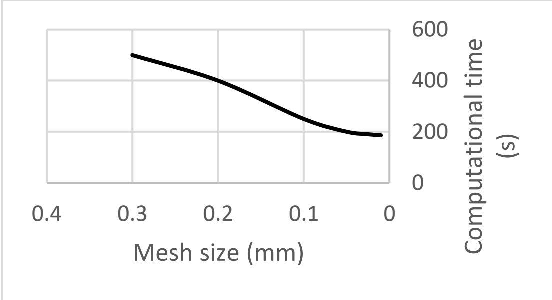

Fig. 3 Mesh sensitivity analysis for the pressing process

3- Results

The stress distribution contour equivalent to Al/Cu sheets fabricated by APB while analyzing finite elements in two, four and eight layer passes is shown in Fig. 4. The images show that as the thickness decreases, the amount of stress applied to the sheets increases. In order to cause more deformation of the sheets at the same time, it is necessary to spend more energy.

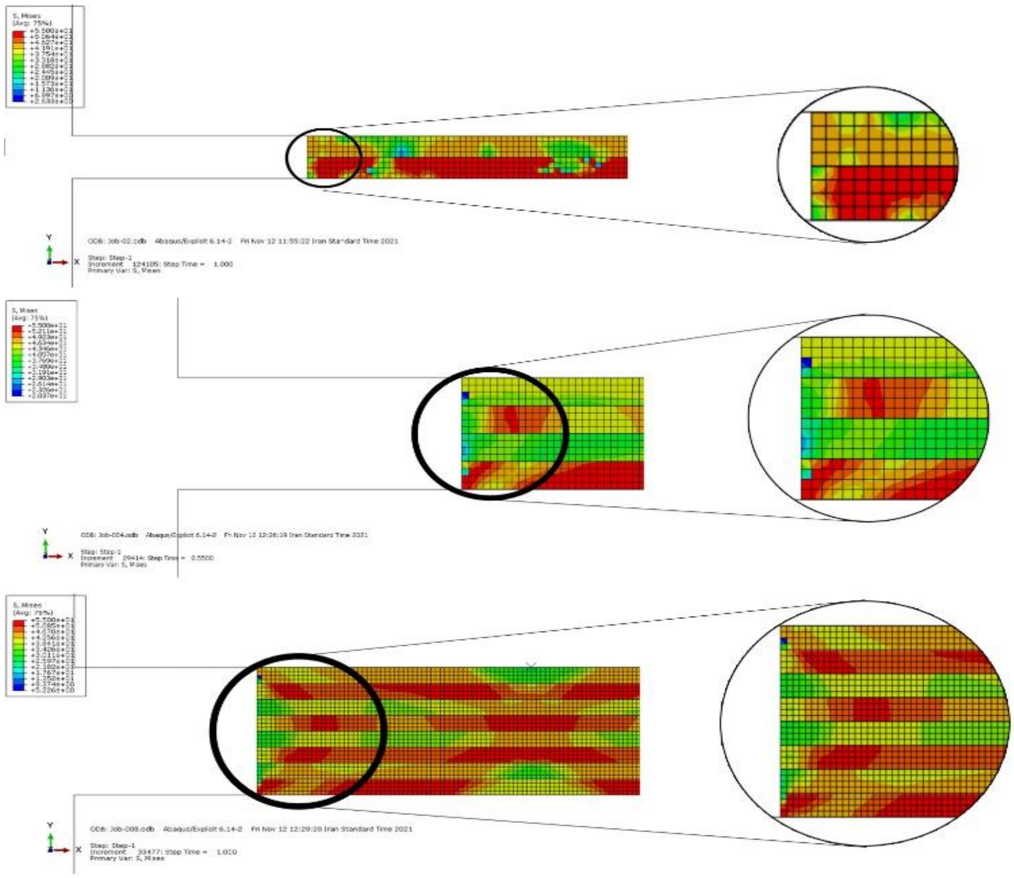

Fig. 4 Contour stress distribution equivalent to copper and aluminum sheets during finite element analysis

Fig. 5 shows the plastic deformation of the composite layers during aggregate forging (pressing), a process performed at room temperature. The plastic deformation is quite uniform and continuous and has been able to create a good relationship between the composite layers. Therefore, with increasing number of passes, which is associated with increasing the number of layers, this uniformity becomes more and more. In other words, the higher the number of passes, the higher the volume of the virgin metal in the direction of the press, which causes the layers to adhere better to each other. Increasing the number of passes, on the one hand, reduces the size of the holes created at the joint of the two sheets of aluminum and copper, and on the other hand, this good connection causes the layers to adhere during extrusion of the virgin metal during plastic deformation. Fig. 5 shows the plastic deformation of two-, four-, and eight-layer composite sheet layers during pressing.

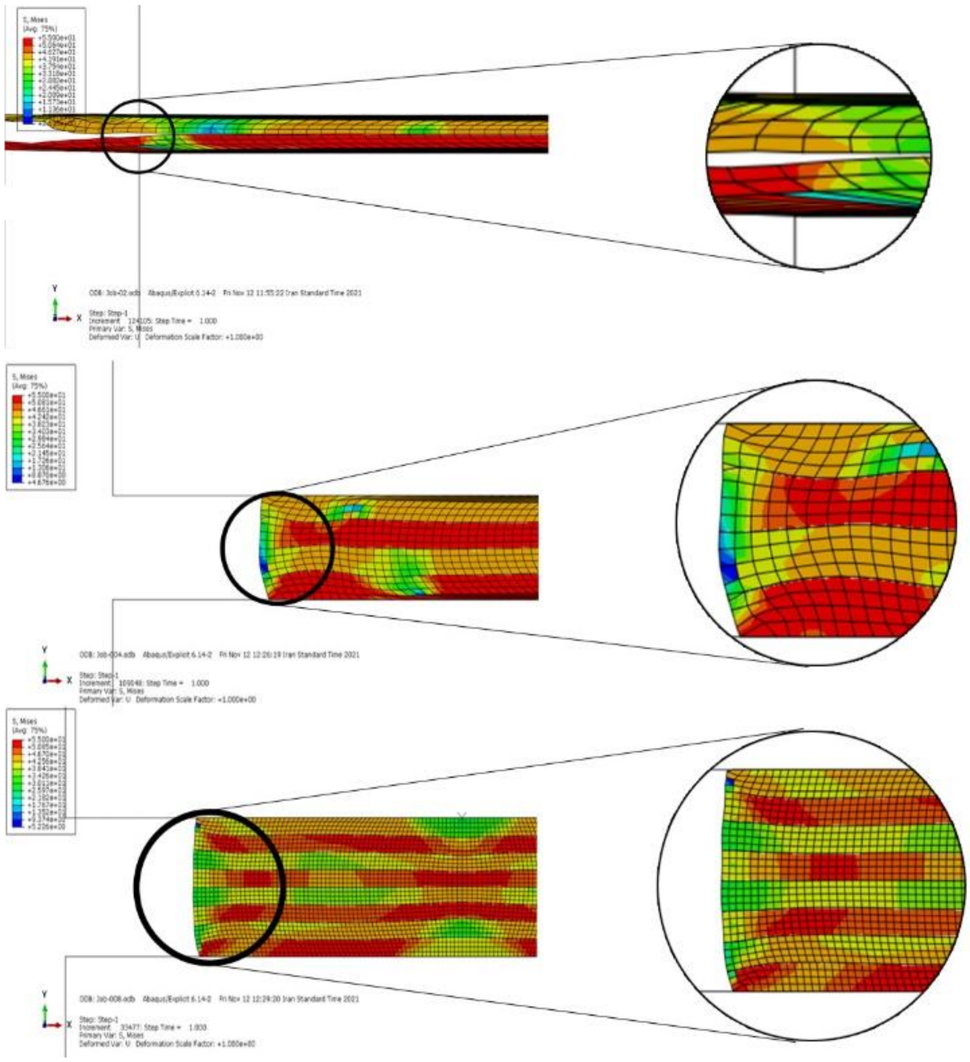

Fig. 5 The plastic shape change of composite sheet layers during pressing

Fig. 6 shows the effect of the number of layers (passes) of the APB process on the distribution of shear stresses. According to Fig. 6, the maximum amount of shear stresses has been done in the joint chapter of the sheet and the mold and in the joint chapter of the layers. Shear stresses have a very good effect on the forming behavior of the virgin metal between the layers. Therefore, the higher is the amount of these stresses in the joint of the layers, the more is the interlayer adhesion and ultimately the strength between the layers' increases.

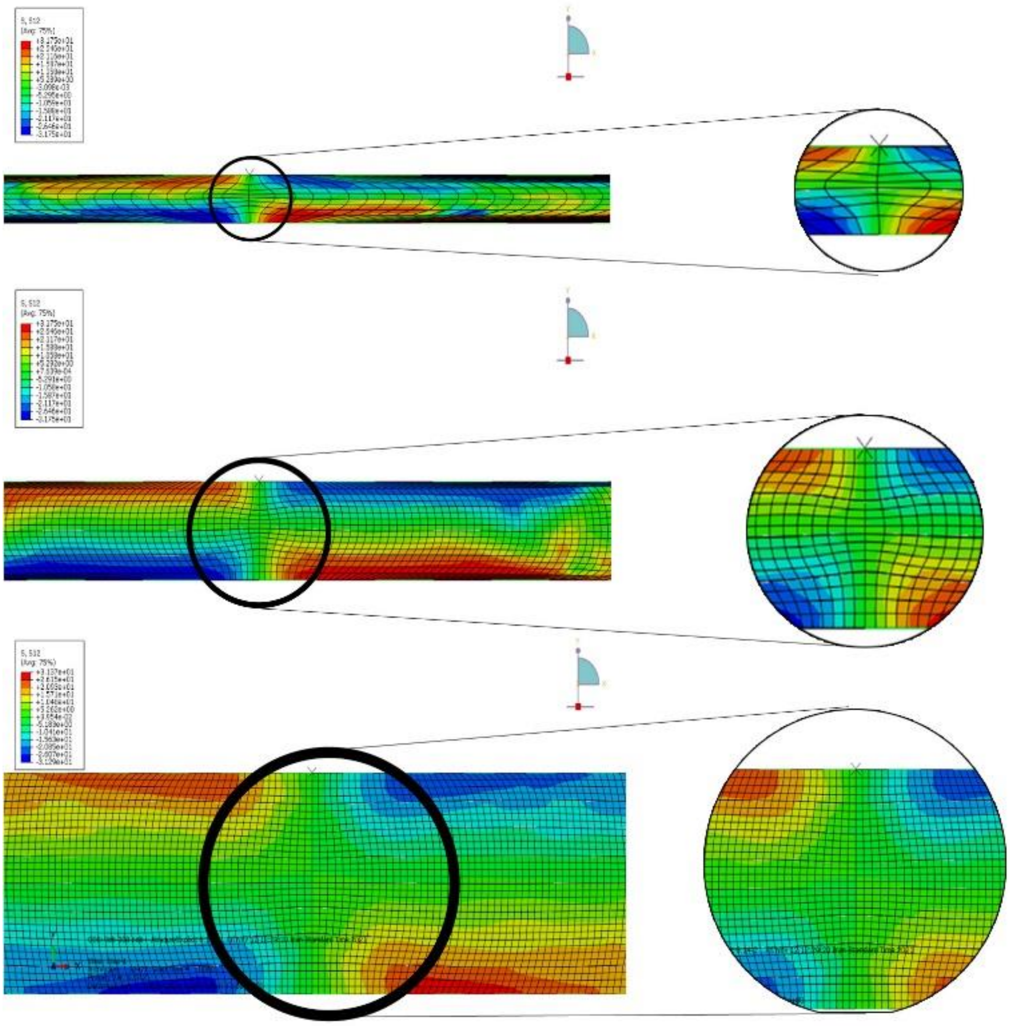

Fig. 6 How to distribute shear stresses based on the number of layers

Then, the bond among the copper and aluminum composite layers is investigated to find the connection between the layers. The outcomes show that owing to the higher strength of copper, the strain hardening of copper is greater than that of aluminum alloy through a composite matrix. Therefore, for fabricated samples, the thinning of both of these metals is the same, and in more passes of the APB process, the copper thickness begins to change due to the heterogeneous deformation. As shown in Fig. 7 [16], after each step, the Cu layer begins to necking in many areas with more distortion.

According to Fig. 8, the tendency to break faster in the third pass has grown. Thus, growth in strain values and strength of the samples through the APB process will increase the toughness of the composites.

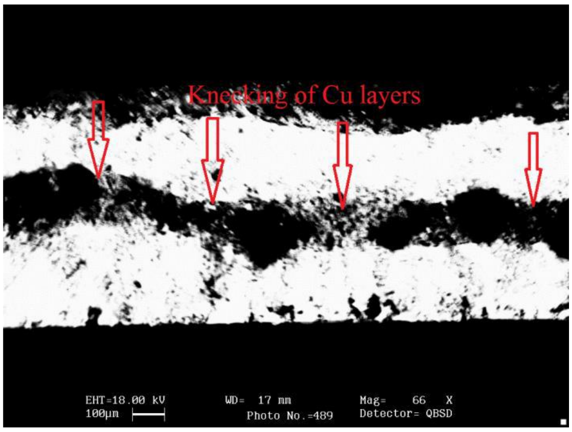

Fig. 7 Schematic creation of metallic connection between layers

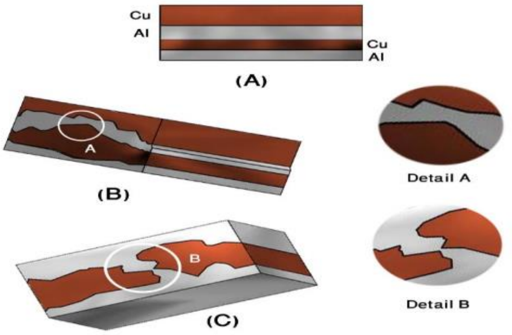

Fig. 8 Graphic images of knecking after APB process

As specified in Fig. 9, the transplantation between copper and aluminum dipping has occurred with increasing pressure load. For this reason, with increasing APB process, hardness increases gradually.

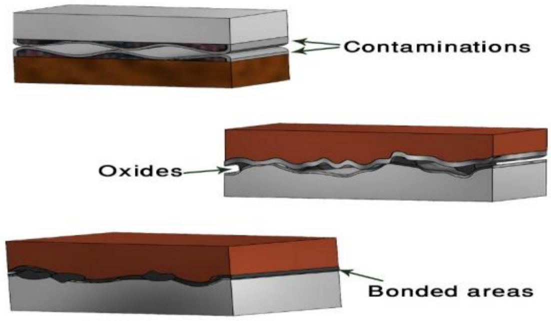

Fig. 9: The progression of the bond between the two layers of Al and Cu under increasing pressure load

Figs. 10 and 11 represent shear stresses in the joint chapter between composite layers. The amount of shear stress decreases by increasing the number of passes due to the work of the layers. In other words, the shear stress between the layers, the amount of virgin metal decreases. But it should be noted that for example, for the third pass, the overall rate of shear stresses is equal to Fig. 10. In this case, the total shear stress increases by increasing the number of passes.

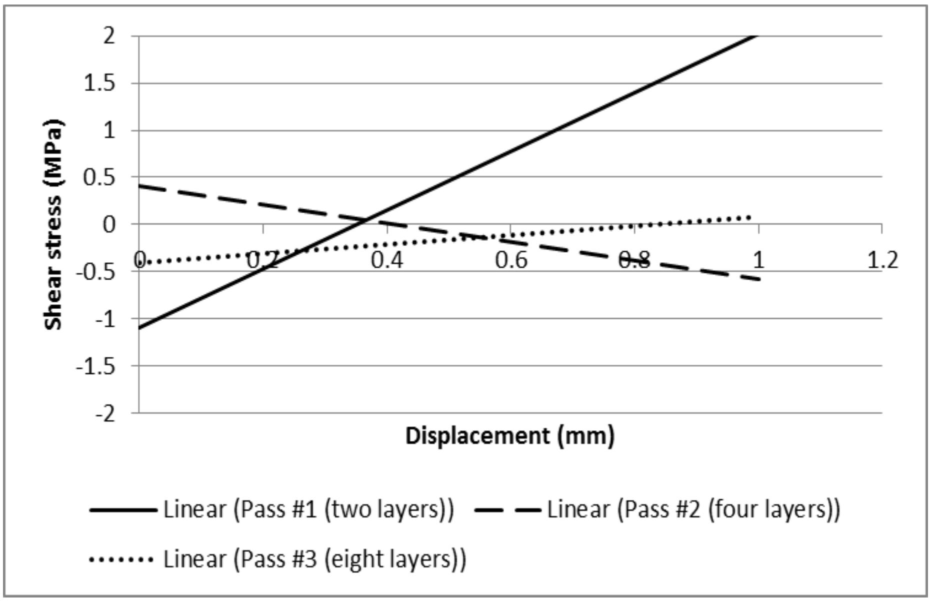

Fig. 10 Shear tensions (for each stage) between the joint chapter of Al/Cu sheets (regardless of the total shear stresses of the previous press steps)

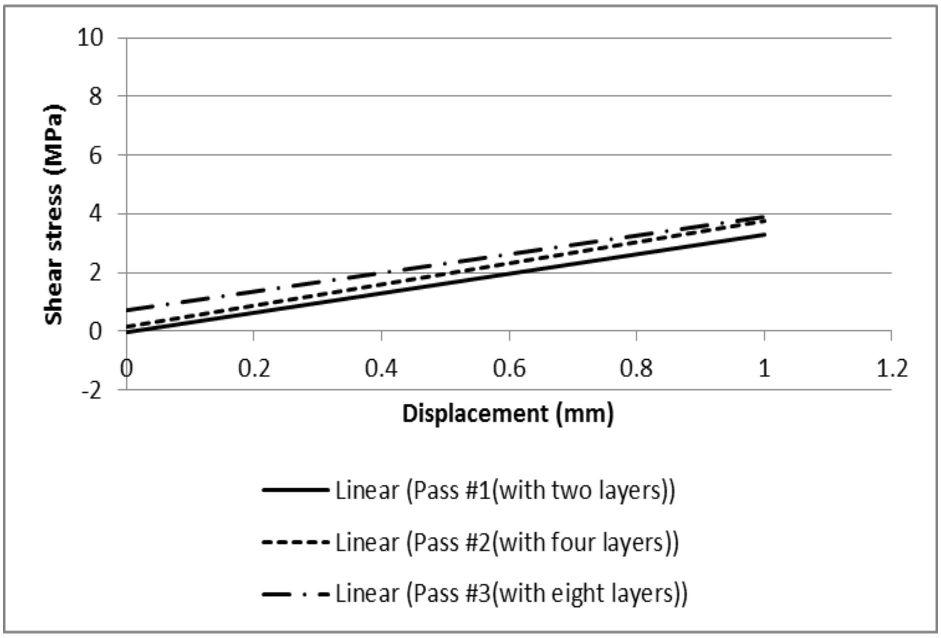

Fig. 11 Total shear stresses between the joint chapter of Al/Cu sheets

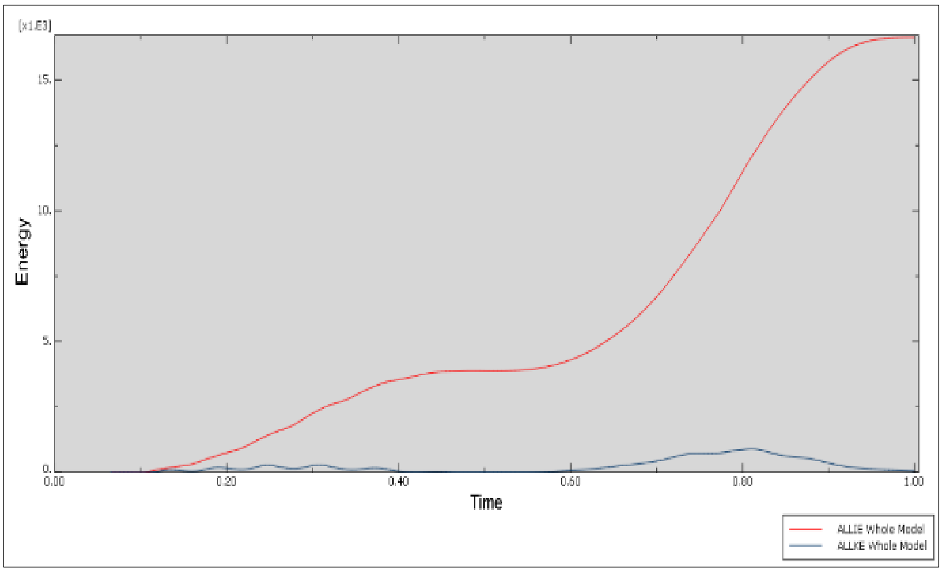

Fig. 12 The ratio of kinetic energy to internal energy

Fig. 12 indicates the ratio of movement energy to the internal energy, with its maximum difference in less than 5%, in other words, indicates that the rate of mass scale used in this simulation is correct and the computational error is at least.

4- Discussion

The results obtained for passes 1 to 3 (two, four and eight layers) represent the plastic form of composite layers during the APB. With regard to the constant temperature of the process (room temperature), temperature changes in this process is not considered.

The modeling of this process was performed by the ABAQUS finite element software and two-dimensional on two, four and eight layers of copper and aluminum. Via the numerical simulator of the process, the effect of the pressure caused by the APB process on the distribution of stress during the process on the two, four and eight layers of sheets was investigated. In the present study, the effects of different parameters such as initial thickness and thickness decrease on the final product and output parameters such as stress, strain, strain rate and force pressure are investigated. The outputs have been investigated in order to investigate the effect of inputs on the unobtrusive material and its mechanical characteristics, which are the results below.

1. With increasing thickness reduction, stress applied on the sheet has increased. The reason is that more energy is needed to change the formulation of more layers in the same time, and with increasing this parameter, the amount of maximum stress increases significantly. Along with increasing thickness decreased, shear stresses between layers have increased.
2. Increasing the temperature reduces the amount of stress and this is due to the easier formability of metals at higher temperatures. Therefore, considering the high probability of occurrence of this phenomenon during the process, the study of temperature effects at the end of the project was omitted.
3. By increasing percentage of thickness decrease is observed that the rate of sinking of the layers in each other increases.
4. In addition to increasing the thickness percentage, more volumes of layers are influenced by plastic shape, which increases normal stresses. By increasing the thickness reduction percent, the shear stresses between layers' increase. Where the shear stress is zero, it's a neutral point. At this point, due to the contrast of shear tensions caused by friction on both sides, the shear stress is zero.
5. With the growth rate of thickness in the layers, the amount of maximum stress has also been significantly increased, which could be guessed before, and here the correctness of calculations with computational simulation is transparent.

5- Conclusion

The results show that the plastic form change during the process has a suitable continuity and uniformity, which has led to an acceptable relationship between copper and aluminum layers. It is also observed that the number of passes increases the size of the virgin metal in the direction of the press has grown, which leads to rising compression and better adhesion of the layers to each other. By increasing the number of passes, reducing the size of the cavities created in the joint chapter of composite sheets occur that the results also confirm this hypothesis. The results show that due to higher copper strength, copper strain is more than aluminum. Therefore, in the number of cumulative iron processes, copper thickness changes, due to heterogeneous shape changes, and begins to broken. Along with the progression of the transplantation between composite layers, the pressure rate increases. Therefore, the range of hardness gradually increases through this process. The results indicate that shear tensions have increased in the joint chapter between Al/Cu layers. Owing to the hardness of the layers, the amount of shear stress decreases by increasing the number of passes.

Finally, the total shear stress increases with increasing number of passes

Disclosure statement

No potential conflict of interest was reported by the author(s).

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