Study on Effective Parameters on Cold Forming of pressure vessel Sheets

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Abstract

In this study, the cold formation of pressure vessel sheet was investigated by using open-die pressing process. The rolled sheet of A516 Gr70 with a thickness of 45 mm was selected. The radius of the die was 6000 mm to pressing process. The process was carried out in three passes. In each pass, force of 600 tons was applied. The process was performed in passes 1, 2 and 3 in order to reduce the effect of the spring back and to check the effect of the repetition of formation process on mechanical properties and microstructure of the formed sheets. The results showed that the tensile strength, yield stress and hardness are reduced at the first step of pressing process. In the following, the mechanical properties are increased by repeating the pressing process in 2 and 3 passes. Microstructural analysis showed that the order of rolling grains was disrupted and the orientation of the first grains would greatly change by performing the pressing process. By increasing the number of passes, the orientation of the grains become more uniform that causes the enhancement of mechanical properties.

Keywords*:* **Open-die pressing, Pressure vessel, Mechanical properties.**

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1. Introduction

ASTM A516 steel is carbon-manganese steel or ferrite steel which is used based on ASTM standard for Manufacturing of pressure vessels and equipment in lower or medium temperature and also for those equipments that the toughness of the materials are their main concern [1-2]. In industry, the pressure vessels are made of A516 sheet in 55, 60, 65, and 70 grades. However, the most common sheet in the construction of pressure vessels is A516-Gr 70.

A516-Gr70 steel is widely used in atomic industry, pressure vessels, rail industry, petrochemical, and oil and mining industries, due to relatively good failure characteristics [1-3]. The main reason for widespread use of A516 steel sheet in the construction of pressure vessels is having the desired flexibility and strength synchronically and its ability to absorb energy at low temperature. Due to the high pressure condition, the wall of pressure vessels is always prone to the creation of death-incidents and this fact has led to use some important processes in the construction of such equipment [2-7]. Based on ASME SEC VIII standard, the pressure vessels refer to those that their interior design pressure are more than 15 psi (and less than 3000 psi) [8]. These tanks are usually cylindrical or spherical. They are used for maintaining or carrying out the chemical processes for liquids or gases which have the ability to withstand various loading (such as internal pressure, external pressure and vacuum inside). In the crust of many pressure vessels, depending on the conditions and the thickness of the tanks wall, the iron sheet are used in form of coil and rolled sheets that are bent by the formation process. The main usage of these thick wall tanks is in petroleum and gas industries and also petrochemicals.

The main aim of this study is to investigate the effect of the formation process by using open-die pressing on mechanical properties and microstructural properties of A516-Gr70 sheet. In addition, the effect of the repetition of the process was investigated on the mechanical properties and finding the reason for that.

2. Materials and Methods

In this study A516-Gr70 steel sheet was used with dimensions of 45*400*2000 mm. The chemical composition of this sheet is listed in Table 1.

Table 1: Chemical composition of steel sheet

Element	C	Si	S	P	Mn	Ni	Cr	Cu	Si	Al
Weight percent%	0.16	0.23	0.012	0.012	0.99	0.08	0.06	0.01	0.12	0.03

In order to form A516-Gr70 sheet and to investigate the effect of formation process and its repetition of mechanical properties and microstructure, (the repletion of the process is done in order to pinpoint and reduce the amount of spring back) the hydraulic process with the force of 600 tons was used. It should be noted that the used sheet was produced by rolling process. For forming the sheet in shape of the wall of pressure vessels the Cold Work Process was used. The execution of the process, in order to form the mentioned sheet, was based on the open-die procedure which was carried out with the punch force and the die with the radius of 6000 mm. To do the process, after placing the sheet in the die, the force of 600 tons was applied and after applying the force, from the mentioned sheet some specimens were selected to study the microstructure and mechanical properties. In order to investigate the effect of process repetition on mechanical properties and microstructure, the process was repeated in 2 and 3 passes and in each stage, some specimens were selected to study the mechanical properties and microstructure from formed sheet. In order to investigate the changing energy of impact after each pass and to compare it to the original sample sheet (rolled sheet) the specimens were prepared in accordance to the ASTM A370 standard that are shown schematically in Figure.1.

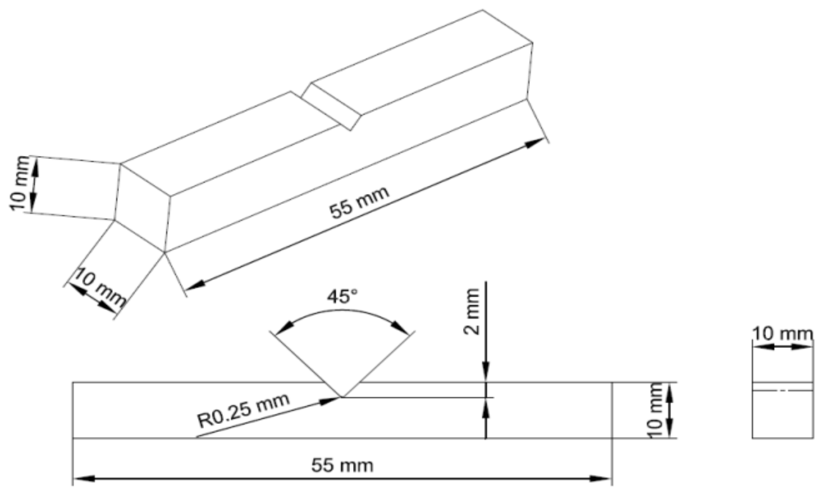

Figure 1. Shape of sample prepared for impact test

The specimens were prepared to examine the impact resistance in the longitudinal direction (at the direction of rolling). Sharp Impact Test at -49°C was carried out on the first sample sheet and on the formed sheet after 1, 2, and 3 passes. To deliver the parts to the desired temperature, the specimens were immersed in a mixture of Nitrogen and Methanol. It should be mentioned that the impact test machine, Santam machine, is made in Iran. In order to study the tensile properties, the tensile test specimens were prepared based on ASTM A370 standard which is schematically represented in Figure.2.

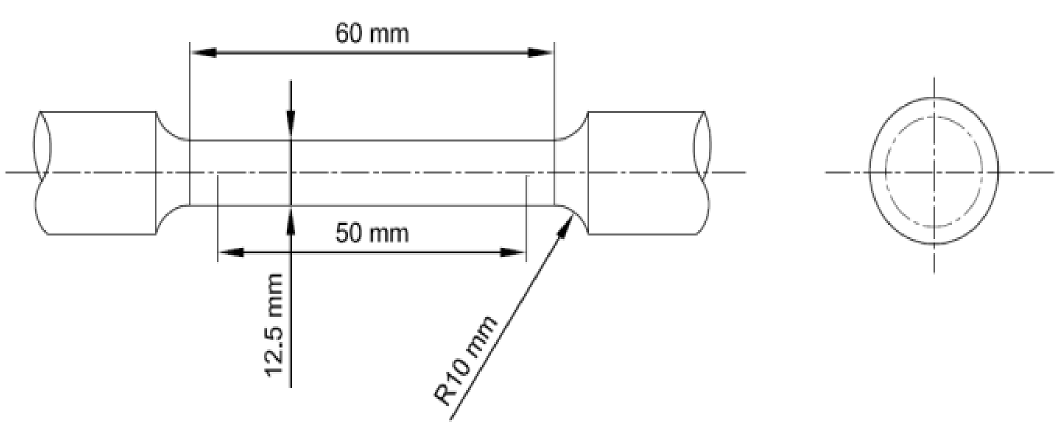

Figure 2. Shape of sample prepared for tensile test

The tensile test device, Zwick machine used in this study is made by Germany. In order to investigate the changing hardness on the passes and to compare it to the original sample sheet the specimens were prepared. The hardness test machine, SwissRock machine, is made in Swiss.

Also, to investigate the microstructure of the parts some specimens were made of the original sheet and the formed sheet. They were polished with Nital 2% solution then they were studied by a light microscope. To determine the fracture surface of the tensile specimens and to determine the type of soft and brittle fracture, the scanning election microscope was used.

3. Results and Discussion

The hardness are shown in Table 2 and the tensile test results are shown in Table 3 and Figure.3.

Table 2: The hardness of the sheet before and after deformation

Sample Name	Hardness(HB)
Initial Plate	163
One Pass	155
Two Passes	159
Three passes	161

Table 3: Tensile properties of the sheet before and after deformation

Sample Name	Yield stress(MPa)	Tensile strength(MPa)	Strain Failure%
Initial Plate	396	539	30
One Pass	331	506	26
Two Passes	335	520	28
Three passes	354	528	29

As it can be seen, hardness and yield stress and tensile strength and strain failure is reduced after the pressing process in comparison by the original sheet. The main reason is the Bauchinger effect and disorganization of microstructure. Figure.4 illustrates the metallographic image.

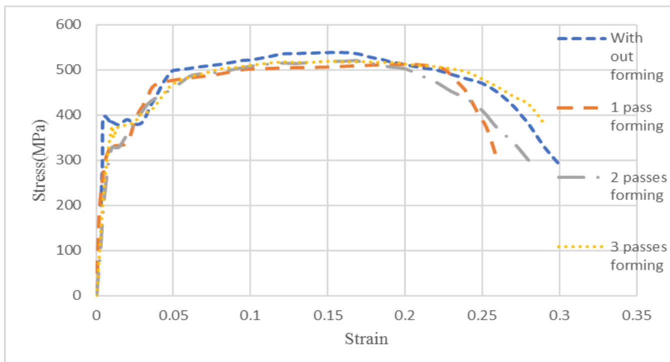

Figure 3. Engineering stress-strain curve of the sheet before and after deformation.

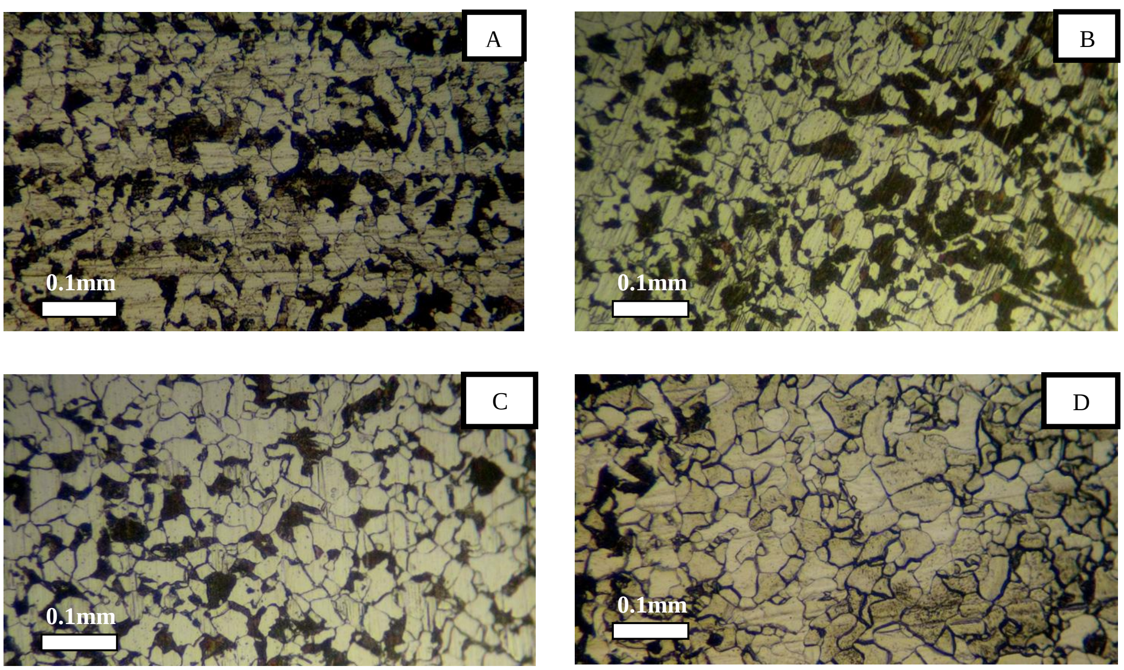

Figure 4. Optical micrograph A516 Gr70 steel specimens before and after pressing, A) Rolling sheet (before pressing), B) One pass, C) Two passes, D)Three passes

As it is observed, the disorganization of microstructures after the first pass of the formation is visible. On the other hand, the bonding between the grains has been completely eliminated by executing the process .The Bauchinger effect, after the process of rolling sheet, plays an important role in reducing mechanical properties. This phenomenon is very important in the process of bending steel plate. Besides, the metals are highly cold work due to the process and when they are exposed to the tension with an opposite sign, soft work occurs on them. The Bauchinger mechanism is hidden in the process of cold work. Orowan has mentioned that during the plastic deformation, there are a number of dislocations in the nodes of the barriers and finally it leads to the formation of some cells [9]. After loading, due to the mechanical stability of the structure, the dislocation lines cannot move too much easily. In this regard, when loading is reversed, a number of dislocation lines at Low stress can move in a great distance, because the barriers behind the dislocation lines, like the obstacles that are immediately formed in front of them, are probably not so strict and close to each other. In fact, this action causes the initial yield occurs in lower stress when loading is reversed [9]. The reason for reduction of yield stress and tensile strength in deformation specimens in compare to the specimens without deformation is due to the Bauchinger effect and the removal of texture and bonding in the microstructure. Considering this fact that deformation of these specimens were Cold Work and they were done by compressive force, therefor, the Bauchinger phenomenon is occurred due to the residual compression stress in the grains after the tensile plastic deformation [10]. As shown in Figure.4, the results of metallography indicate that in the rolled specimen, the grains are rotated in the same direction and they are in the direction of rolling process which, by executing of formation process and compressive force of press, the structure and grains orientation have changed, so the texture and regular arrangement of the structure disappears. This is also important in reducing hardness and tensile properties. On the other hand, by repeating the forming process in 2 or 3 stages, disordering of microstructure decreased and the grains are oriented to the compressive forced of the press. Therefore, this would improve the mechanical properties. The results of the impact test at -49 °C are shown in Table 4.

Table4: The impact test energy at -49 °C of the sheet before and after deformation

Sample Name	Impact test energy at -49 °C
Initial Plate	95 J
One Pass	40 J
Two Passes	63 J
Three passes	73 J

It is presented that the highest impact energy is dedicated to the rolled specimen that has grains in the same direction of rolling and its structure has bondings. Also the number of grains with sharp edges is less in its microstructure in compared to the deformed specimens. Strengthening mechanism in the best microstructure for combination of toughness with strength is the strengthening by the particles that have a strong connection with the field, so that it prevents the formation of small holes [11] and this microstructure is clearly obvious in the metallographic specimen in Figure.4A. Therefore, by executing the formation process and eliminating the order in the microstructure and changing the orientation of the grains, some holes are made in the microstructure and the grain boundaries. As a result of formation process, the crushing of grains take place and the number of grains with sharp edges increases and it leads to the impact reduction. Besides, by the repetition of the forming stage and regularization of the microstructure and the organization of the grains and the loss of holes, the energy of the impact increases.

In Figure 5, the fracture surface of the original specimen sheet and deformed sheets are shown in 1, 2, and 3 passes of the process.

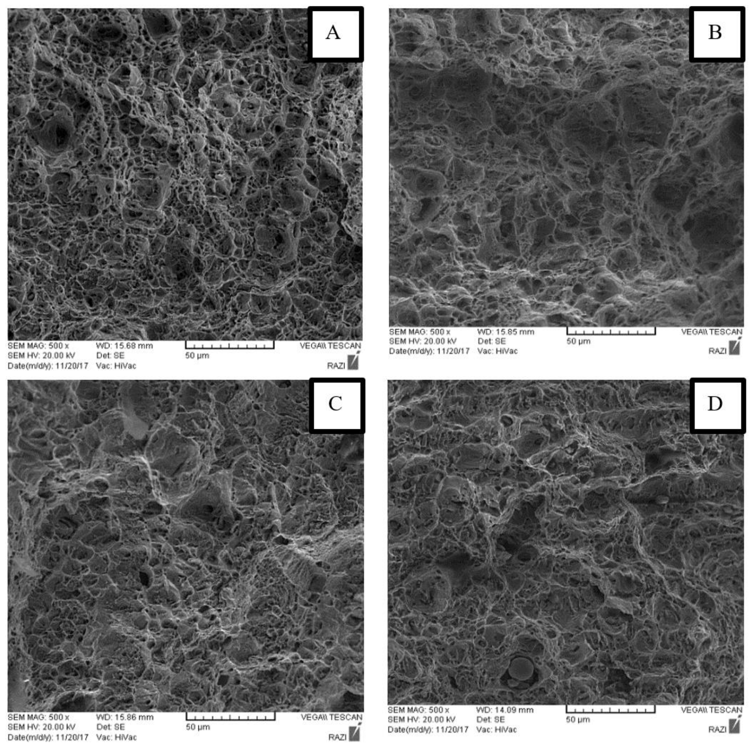

Figure 5. SEM image of the fracture surface after tensile test before and after pressing, A) Rolling sheet (before pressing), B)One pass, C) Two passes, D)Three passes

Figure 5 a is shown the presence of dimples at the fracture surface of original rolling sheet in soft failure. By executing the formation process with press at the first stage of formation, Figure.5b, disorganization of the microstructure and the loss of the bonding between the particles, different orientation of the grains to each other, the amount of dimples at the fracture surface decreases. In this case, the cleavage surfaces at the fracture surface are more likely to be seen, which is due to the brittle failure. By repeating the formation process in 2 stages, the microstructure becomes more uniform and at the fracture surface, the presence of dimples increases in compare to the 1 stage formation process. At the fracture surface of the third stage of formation process (Figure. 5 d), microstructure becomes more uniform and the grains are more in line in compare to the specimens before the presence of dimples and also ductile failure has occurred.

4. Conclusion

1) By executing the formation process on A516-Gr70 rolling sheet, the compressive force reduces the tensile properties that is due to the Bauchinger effect and eliminating the bonding between grains.

2) The results of tensile and micrographic tests showed that, by repeating the formation process by pressing, due to the reduction of disorder in the microstructure and a uniform microstructure, mechanical properties are improved.

3) The results of the impact test at -49°C showed that, by executing formation process with press, the microstructure becomes more uniform. By creating some grains with sharp edges, the impact resistance decreased at first and then it increased by repeating the process and decreasing the amount of irregularity in the microstructure.

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6. References

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