Explosive Pressing Experiment and Its Challenges to Conduct it on University Level

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Abstract. Typical press force for hydraulic press machine for most universities are around 10 to 30 ton. For higher load, student uses Ultimate Testing Machine (UTM). Typical press force for UTM for higher learning institution is 300 ton. To obtain more press force, the specimen must be small. This is according to force equation where the smaller the surface area, the higher the force generated on it. However, the problem with small specimen is that it is difficult for researchers to do further investigations for hardness test, tensile test and microstructural analysis. Besides, there is a limit to maximum force a UTM machine can give. This paper presents steps for doing experiments using explosive pressing at university level. The explosive pressing apparatus was an improved designed by the same author. This experiment uses an amount of explosive that is place at top of the apparatus. The experiment is done underground for safety purposes. Explosive handling was done with help from authorized explosive expert. Major benefits of explosive pressing are larger samples can be pressed and the press force is very high. This paper will discuss the steps to do experiment and the challenges while doing explosive pressing using this apparatus. This paper will also show that higher pressing force can lead to finer microstructure of material being pressed.

1. Introduction

For pressing experiment, students have two options, using hydraulic press or using UTM. Typical hydraulic press machine can press around 30 ton to 50 ton while typical UTM can reach 300-ton maximum load. UTM is a testing machine that is widely used in all institutions of higher learning. UTM can do various tests such as tensile tests, three-point bending tests, compression tests and pressing. Examples of specimens tested are composites, alloys, steels and green samples. Among notable brands are Instron, Shimadzu and Santam. On average, the maximum load a UTM machine can achieve is 300kN or 300 ton, testing width 600 mm and displacement rate, 500 mm/min. [1]–[3]. Explosive research at university level is rarely done because of its danger and limited access to explosive material. Fortunately, the authors can do the experiment with help by experts from National Defence University Malaysia (NDUM). When properly channelled, energy from explosive produces higher press force than UTM. The explosive force produces shock wave that improves particle bonding and increases density of product. [4], [5]. Notable researches on explosive pressing was mostly done in China and Russia. Their experiment setup uses tubular cores that is enclosed with explosives. There is other research that encloses a cylindrical tube with explosives. Most of their study focuses on pressing sandwich material to see the effect at higher press force. [6]–[8]. This research places the explosive at the top of the plunger. The plunger thickness determines the press force. The thinner the plunger, more force can be press on the specimen. Previous design apparatus
by the same author shows a big and bulky apparatus that is difficult for handling [4]. This paper will show improvements for the design, discussion on experimental steps for doing explosive pressing experiment and the challenges in doing experiment.

2. Experimental
Experiments involving live explosion must be done with help from experts at NDUM. The project leader will do all the arrangements with NDUM. At the arranged date, all team members travel to blast site. Explosive pressing experiments is a team effort. To ease of experiment, at least 6 persons must be involved. 2 persons handles the explosives matter along with explosive expert. 4 persons will do the digging and all physical works. First team digs the hole at demolition site. The hole depth is about 2 feet. The hole should fit a plywood that acts as the base. Second team handles the explosive preparation. They measure the thickness as well as moulding the explosive according to dimension. Explosive expert will assist them. Once the hole is prepared, the apparatus is placed on the plywood. Once ready, the apparatus is buried. One person must hold the apparatus while being buried to avoid it topple down. Then the explosive and the specimen is carefully placed on its position. Handling of explosives is done by explosive expert. To add more strength, several sandbags is placed vertically on the blast apparatus. The explosive expert will ask everyone to be at safe distance while they do the final checking. Then they trigger the explosion. After blast, researchers went to blast area. The blast area is examined thoroughly. The specimen is retrieved. If the specimen is missing or parts of the blast apparatus got thrown away due to explosive effect, perimeter check must be done to find them. The blast test is repeated until all specimen is completed. After all experiments are completed, the blast test site is cleared. Figure 1 shows the flowchart for steps in doing explosive pressing experiment. Table 1 shows list of equipment for explosive pressing test.

![Figure 1. Flow Chart for the Explosive Pressing Experiment](image-url)
Table 1. The list of equipment are as follows

| No | Equipment            | Purpose                                           |
|----|----------------------|---------------------------------------------------|
| 1  | Emulex               | A type of Explosive                               |
| 2  | Detonator            | Explosive connector                              |
| 3  | Sensors              | For any measurements                             |
| 4  | Plastic container    | Store the specimen                               |
| 5  | Plywood 2 feet x 2 feet | As a foundation to put on the ground          |
| 6  | Shell cover          | To cover the apparatus for underground explosion |
| 7  | Shovel               | To dig hole                                      |
| 8  | Explosive pressing apparatus |                                           |

The explosive pressing apparatus is an improved design from the same author in [4]. Figure 2 shows the apparatus. The apparatus consists of a plunger, mold, shell cover and lower base. The specimen is place inside the mold. Then plunger is put on to it. Plywood is layout on the ground to assist levelling. While buried, one person must hold the apparatus to avoid it topple down. Emulex which is a type of explosive is place on top of the plunger. The specimen in this research is iron powder.

Figure 2. Explosive pressing apparatus
3. Analytical analysis

Analytical analysis shows all the equations used to calculate force impacted on the specimen. The formula starts with simple stress equation followed by energy equation, jet velocity and followed by stress wave propagation. Finally, the force is calculated by deriving the impact calculation.

3.1 Force produced by Emulex

The stress produced can be calculated based on the following equation:

From Eq. (1)

\[ \sigma = \frac{m \left( \frac{v}{t} \right)}{A} \]  

Where,

- \( m \) = mass (kg)
- \( v \) = velocity (m/s)
- \( t \) = time (s)
- \( A \) = area (m²)

The energy produced can be calculated based on the following equation:

From Eq. (2) (Henry, 1967)

\[ V_o = \sqrt{2e \left( \frac{m}{c} + \frac{1}{2} \right)^{-\frac{1}{2}}} \]  

Where;

- \( m \) = Mass of Casing
- \( c \) = Mass of explosive

The jet velocity produced by Emulex can be calculated based on the following equation:

From Eq. (3)

\[ v = \sqrt{\frac{2E}{m}} \]  

Where;

- \( E \) = Internal energy produced by Emulex
m = Mass of explosive

3.2 Stress Propagation in Plunger
The stress propagation in plunger can be calculated using the equation:

From Eq. (9) [9]

\[ C_p = \sqrt{\frac{d_\sigma}{d_\varepsilon}} \rho \]  

(4)

Where,

\[ d_\sigma = \frac{F}{A} \]  

(5)

F = force produced by Emulex
A = area of plunger \((m^2)\)
\(\rho = \) density of tool steel \(\left(\frac{kg}{m^3}\right)\)

Where,

\[ d_\varepsilon = \frac{\varepsilon \text{ lateral}}{\varepsilon \text{ horizontal}} \]  

(6)

Then,

\[ d_\varepsilon = \Delta l_f \frac{l_i}{l_0} \]  

(7)

Therefore;

\[ C_p = \sqrt{\frac{F}{l \times h}} \frac{\Delta l_f}{\Delta l_0} \frac{l_i}{l_0} \frac{1}{\rho} \]  

(8)

3.3 Force produced impacted on powder metal

From the Eq. (14) [10]

\[ \frac{V_1}{V_0} = \left[ \frac{1-m(V_0)^2(1-\gamma_{pw})}{2PV_0} \right]^{\frac{1}{1-\gamma_{pw}}} \]  

(9)

\(V_0 = \) Volume initial \((m^3)\)
\(V_1 = \) Volume final \((m^3)\)
m = Mass of plunger \((N)\)
v = Velocity produced \((m/s)\)
\[ \rho = \text{Density} \]

Where \( \gamma = 10^{-9} \)

Therefore

\[ P = \frac{(\gamma_{pw}-1)m(\sqrt{\frac{V_1}{V_0}})^{\gamma_{pw}}}{2(V_1-V_0)(\frac{V_1}{V_0})} \quad (10) \]

### 4. Results and discussion

From the research, it can be stated that the higher amount of Emulex used to give a higher value of pressing force beyond 50,000 ton pressed. The results give a good achievement for powder metallurgy method. From the analysis, the Iron powder after the explosive pressing has a high density and hardness. The higher the pressing force the higher the density of the Iron formed. The hardness of Iron also increases with the increment of pressing force. Moreover, the SEM analysis also was done to the specimen. The microstructure of Iron powder was compared by using different amount of Emulex increases from 1000g to 2000g of Emulex. The porosity shown by the SEM was decrease because the higher force can produce effective binding of the Iron particle. The increment the mass of Emulex leads to a reduction in porosity. The density of Iron increases with the reduction of pore and increment of cold-welded region. Thus, it can be stated that the finer microstructure can be obtained using a higher pressing force and the explosive pressing can produce a smooth microstructure of metal with low porosity.

#### 4.1 Pressing results

The explosive used is Emulex (Austin Powder, 2013). The Emulex is form into shape charge due to more pressing force. The pressing material is sintered to fortify the holding between particles. Investigation of minimized powder microstructure is performed using checking Scanning Electron Microscope (SEM). The hardness of powder checked by Rockwell Digital Hardness and the outcome demonstrates the hardness of minimal powder for explosive was 50.6 HRA, while the reduced powder using Universal Testing Machine is 24.0 HRA. Microstructure comes about showed lesser porosity utilizing touchy pressing. To compare with UTM, explosive pressing gives better microstructural results. UTM can produce press force limited to 300 ton while explosive pressing can reach 50,000 ton. The differences are very high. Some basic press theory for both method but for explosive pressing, the results show better and finer microstructural results. However explosive pressing have challenges as discussed below.

#### 4.2 Challenges

Upon doing blast test, there are points for improvements. This paper discusses the problems related to doing the experiment and improvements to the blast method for future research.

##### 4.2.1 Interval time

The average time taken for each blast test is 25 minutes. This is because the authors have to dig the samples, asses the results, doing minor adjustments for the blast apparatus, flatten the
ground, levelling the apparatus and keeping a safe distance from blast site. Therefore, for a period of 9 hours beginning at 9 a.m to 7 p.m, there can be 16 tests can be done per day. No blast is done during lunch time. Therefore, the blast session must be plan carefully. To save time, it is suggested that two set of explosive pressing apparatus is prepared. Two blast can be triggered at one time.

4.2.2 Lost parts and specimens
Due to tremendous force generated from explosive, some parts of explosive apparatus may get thrown away. Once, the specimen got thrown away also. Therefore, after each blast, the first thing to check is the perimeter to see if there are some parts of the apparatus got thrown away. Then when digging back the apparatus, make sure all parts are there. Most importantly the specimen should be intact. As a precaution, sandbags are put on the perimeter of the hole. During blast event, the sand will mitigate the blast effect while reducing possibilities of parts got thrown away.

4.2.3 Damage parts
Since explosive gives tremendous loads, some parts are expected to damage. Parts that will damage are plunger, sandbags and plywood. However, the lower base, the shell cover and the mold must not be damage. Since blast load is unpredictable, always start the experiment with lower amount of explosive then increase it incrementally. From experience, explosive weight more than 1.6 kg may damage the mold. Lower base can survive any load if it is indirect blast.

4.2.4 Cost to do explosive experiment
It is expensive to do an explosive pressing session. Usually the test is set to be two days. Beginning Friday evening and finishes on Saturday evening. It may be extended to Sunday if necessary. The cost covers lodging, meals, consultancy, fees for NDUM and also fees for explosive team. Although it is expensive, the cost is reasonable. To save cost, usually two or more separate blast session is done concurrently with other researchers. To cost is shared by them all.

4.2.5 Sensors
Due to tremendous loads by explosive, any sensors directly in contact with explosive will damage. Sensors with lower specification cannot display the peak pressure readings. High specification pressure sensors are expensive. Therefore, to get reading to calculate force on the specimen, copper crusher method is used. The method was used to examine pressure in the rifle bore during World War II. Pressure from rifle bore will crush the copper. Then the displacement measurement is taken and compare with a table that shows pressure inside the bore. The principle behind copper crusher is stress-strain theory. For explosive pressing purpose, to get the force directly impact on the specimen, mild steel is put as the target. Once impacted by plunger, the mild steel will deform. The height of mild steel is taken before and after blast. From the displacement, strain can be obtained. Modulus of elasticity of mild steel can be obtained from various sources. By calculating the area of specimen, the force directly impacted the specimen can be obtained. It is recommended that two sets of experiments are
done. One with using mild steel as a method to know the force on the sample. One with using the real specimen. Other configurations should be the same.

4.2.6 Accuracy of data
Since blast event is unpredictable, many factors will influence the blast results. For example, different arrangements of sandbags will give different results. Most importantly, the Emulex explosive should be properly compacted. There should be no pores inside the explosive as it will give different results. Therefore, configurations should be the same for all experiments. For explosive, it is suggested to replace Emulex with booster. Booster is Standard booster is 400 grams High Explosive. It has the same geometry and weight. There is no need for a person to mold the explosive to become any shape.

5. Conclusion
From the research, it can be stated that the higher amount of Emulex used to give a higher value of pressing force. The results give a good achievement for powder metallurgy method. From the analysis, the Iron powder after the explosive pressing has a high density and hardness. The higher the pressing force the higher the density of the Iron formed. The hardness of Iron also increases with the increment of pressing force. Moreover, the SEM analysis also was done to the specimen. The microstructure of Iron powder was compared by using different amount of Emulex increases from 1000g to 2000g of Emulex. The porosity shown by the SEM was decrease because the higher force can produce effective binding of the Iron particle. The increment the mass of Emulex leads to a reduction in porosity. The density of Iron increases with the reduction of pore and increment of cold-welded region. Thus, it can be stated that the finer microstructure can be obtained using a higher pressing force and the explosive pressing can produce a smooth microstructure of metal with low porosity. Explosive pressing experiment is expensive and challenging. It involves team effort. However, it is an exciting experiment to do. When properly done, explosive pressing can give better finding for further research.

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6. References

[1] A. L. Araújo, J. R. Correia, and C. M. M. Soares, “Characterization of Al7075-B4C Composite Fabricated By Powder Compaction Techniques Under Different
Densification Rates,” pp. 1–11, 2015.

[2] R. A. Gonçalves and M. B. Da Silva, “Influence of Copper Content on 6351 Aluminum Alloy Machinability,” Procedia Manuf., vol. 1, pp. 683–695, 2015.

[3] H. Babaei, T. Mirzababaie Mostofi, M. Namdari-Khalilabad, M. Alitavoli, and K. Mohammadi, “Gas mixture detonation method, a novel processing technique for metal powder compaction: Experimental investigation and empirical modeling,” Powder Technol., vol. 315, no. April, pp. 171–181, 2017.

[4] A. H. Hilmi, N. A. Azmi, and A. Ismail, “A method to press powder at 6000 ton using small amount of explosive,” in AIP Conference Proceedings, 2017, vol. 1901.

[5] R. N. Rosdi, N. A. Azmi, N. A. Latheef, A. H. Hilmi, and A. Ismail, “Characteristics of iron (Fe) powder using underground explosion pressing,” in AIP Conference Proceedings, 2018, vol. 2030.

[6] N. A. Adamenko and G. V. Agafonova, “Explosive Pressing of Heat Resistant Polymers and Their Composites with PTFE-4,” Chem. Pet. Eng., vol. 52, no. 7–8, pp. 567–572, 2016.

[7] A. V. Krokhalev, V. O. Kharlamov, S. V. Kuz’min, and V. I. Lysak, “Tribotechnical properties of powder hard alloys of chromium carbide with titanium fabricated by explosive pressing,” Russ. J. Non-Ferrous Met., vol. 55, no. 2, pp. 212–217, 2014.

[8] B. Wang, F. Xie, Z. Li, and H. Zhang, “Explosive compaction of Al2O3 nanopowders,” Ceram. Int., vol. 42, no. 7, pp. 8460–8466, 2016.

[9] W. Walters, “Introduction to Shaped Charges,” no. March, 2007.

[10] N. Yavuz, “Mechanics of Dynamic Powder Compaction,” J. Eng. Sci., vol. 2, no. 2, pp. 129–136, 1996.