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Characteristics of Iron powder when Pressed using Explosive Pressing method

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Abstract. Fine iron powder was pressed by Explosive Pressing using type of explosive; emulsion explosive (Emulex grade 150). The green density, hardness, strength and microstructure of iron compact was studied. The explosive is molded into shape charge to give more pressing energy. The underground explosion was conducted since confined space can give more blast energy. Green compact was sintered at 1000℃ to strengthen the bonding between particles. Analysis of compact powder microstructure was performed using scanning electron microscope (SEM). The hardness of compact powder was tested using Rockwell Digital. Universal testing machine was used to conduct the tensile test. The result shows the hardness of compact powder for explosive pressing was 45.8 HRA to 50.2 HRA. Microstructure results show lesser porosity when the density was increased from 6.046 g/cm^3 to 7.298 g/cm^3. There was a presence of cold welding and mechanical interlocking phenomena at surface of specimen.

1. Introduction

Powder metallurgy is a rapidly growth technology. Development of Powder Metallurgy was growing rapidly along with the growth of automotive, machinery, and the other high end equipment industries. The fabrication technology of Powder Metallurgy iron base parts with high density, high strength and high precision has make a development trend in Powder Metallurgy industry [1][2][3]. Recent development of Powder Metallurgy technology such as, warm compaction (WC), surface densification (SD), hot isostatic pressing (HIP), High Velocity Compaction (HVC) and explosive compaction contributes to produce Powder Metallurgy components with improved mechanical properties and microstructure. Some researches, J.Wang et.al and Khan et al., stated that, the explosive compaction method is restricted due to problems to get the explosive material and low productivity [4][5]. The explosive material can be obtained from Tenaga Kimia Sdn Bhd in Rawang which is the sole company in Malaysia that produces emulsion explosive (Emulex grade 150). As stated, people are not easy to get these explosive materials if does not have a valid license. Therefore, the Institute of Quarrying Malaysia has created a Short Firer course that enables people to obtain a short firer license to get explosive materials. The acquired license may only be used to purchase explosive materials for certain purposes (research study) only and there will be certain permitted conditions.

2. Experimental Procedure

In this research work, pure iron powder without any addictive or lubricant was used to produce iron compact using explosive pressing method. Iron powder was supplied by Sigma-Aldrich, Sweden. The characteristics of this powder was given in Table 1. Then, mass of iron filled in die during pressing was 59.71g for each sample. The iron powder was packed in the die with height 10mm and diameter 50mm of each sample.

Figure 1 shows the graphic illustration setup of explosive pressing method. The explosive pressing setup consists of three main parts; shape charge (explosive), plunger and die. All part of explosive pressing except shape charge was made of P20 steel. The explosive material used in this research was emulsion explosive (Emulex grade 150) with a detonation velocity of 4000 to 5500 m/s. The explosive material was moulded into shape charge since more of the explosive acts in the desired direction, increasing effectiveness, reducing materials and decreasing protection requirement [6]. By ignition the detonator, pressing process was done successfully. Several samples were produced by this method. In order to bring out the sample from the die, the Universal Testing Machine was used to eject the sample from the die. After obtaining the sample, some of their properties are measured.

The green density of the sample was taken using Archimedes principle according to ASTM standard B962 [7]. Then, green samples were sintered at 1000°C respectively. The morphology of the sintered and polished sample was analysed using Scanning Electron Microscope (SEM) model (*Hitachi TM-3000*) Tabletop Microscope. The hardness of the samples was tested using Rockwell Digital Hardness machine. The force that applied to the specimen with a load of 60kg at four parts of the surface area of the specimen using diamond cone indenter. The indent time is 10s.

Table 1. Characteristic of Iron powder

Density (g/cm^3)	Particle size (μm)	Melting point (°C)	Boiling point (°C)
7.86	<10	1535	2861

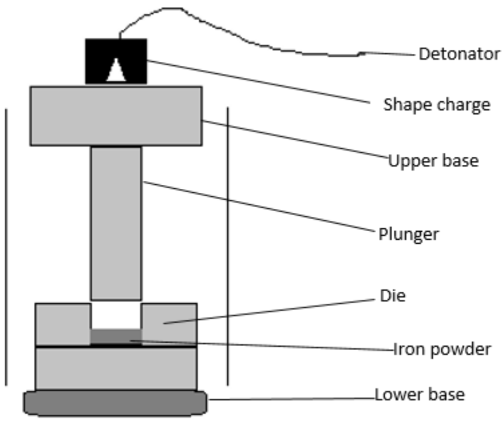

Figure 1. Schematic illustration of explosive pressing apparatus

3. Results and Discussions

3.1. Densification behavior

There are three specimens that had been pressed using Explosive Pressing. The first specimen is pressed with $500g$ of emulsion explosive (Emulex), while the second specimen is pressed using $750g$ of emulsion explosive (Emulex) and the third specimen is pressed using $1000g$ of emulsion explosive (Emulex). Figure 2,3 and 4 shows the green compact of Iron powder after blast test. It can be observed that; the Iron powder had changed its shape from powder to solid state for all specimens.

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Specimen in Figure 2 shows that the green compact is fully compact and does not had crack, while the specimen in Figure 3 shows the surface is smooth and fully compact and specimen in Figure 4 indicates that the green compact also is fully compact during the explosion. The result proved that, the force generated during the experiment is very high until it can press the specimen into a solid metal.

Figure 5 displays the relation of pressing force with green density of specimen. The green density of iron compact increase with the increasing of pressing force. From the graph, at 500g of explosive, the green density of specimen was 6.046 $g/cm^3$with pressing force 13292.252 tonne. The green densities of specimen rise by 36.74 % at 750g of explosive with pressing force 33377.738 tonne. It also can be seen that, the maximum green density that can be obtained from this experiment was 7.298 g/cm^3 with amount of explosive 1000g and pressing force 33991.911 tonne.

As a conclusion, the greater the amount of explosive used, the greater the green densities of Iron compact due to the higher of force generated. Furthermore, the rise in pressing force leads to rise of densification of the Iron compact (Khan et al., 2014) (J Z Wang, Qu, et al., 2009). The densification of Iron compact from this experiment was achieved through a pressing force that created by the explosion energy that transferred to plunger to press the Iron powder. Obviously, the explosive pressing method was better than High-Velocity compaction method since the force generated from explosive pressing is higher than force generated by High-Velocity Compaction which was 1615 N/mm^{-2} that equal to 80.81 ton(Khan et al., 2014).

Figure 2. Green compact of Iron (Specimen 1)

Figure 3. Green compact of Iron (Specimen 2)

Figure 4. Green compact of Iron (Specimen 3)

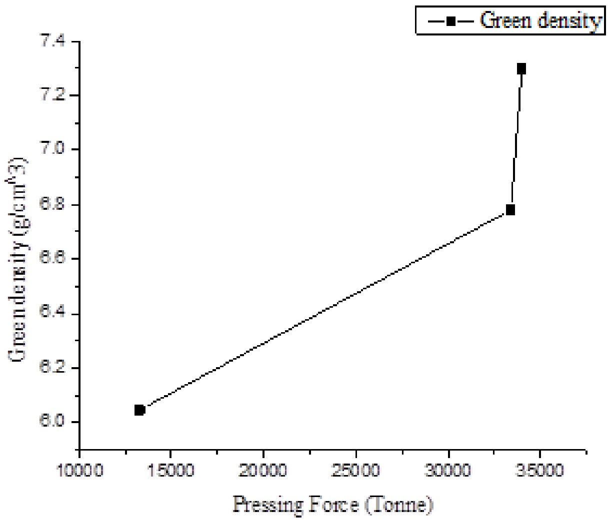

Figure 5. Graph of Green density vs Pressing force

3.2. SEM microstructure

The morphology of the SEM micrograph of Iron was presented in Figure 6,7 and 8. It can be seen that the particles are linked together and show a few pores. The SEM micrograph also shows low porosity since the particles are strongly bond after the sintering process. Besides, the phenomena of cold welding also appear among powder particles due to the less visible of grain boundaries after sintering process. Cold welding in the particle contact contributes to the development of strength in the compact [8].

From Figure 6 to 8, It can be clearly seen that, as the amount of explosive was increased, the porosity decreases, because high pressing force can produce the effective binding of particles. At 500g of explosive, there are many big pores and small pores appears on the SEM image. When the amount of explosive was increased to 750g, the pores are reduced. Then, at the highest amount of explosive which was 1000g, there was only small pores exist on the SEM image.

The strength of compact powder was depending on two phenomena which were cold welding and mechanical interlocking. The phenomena of cold welding occur at high pressing pressure. From figure, it can be obtained that, at 500g of explosive, the cold welding phenomena not appears since the grain boundary is visible. Then, at 750g and 1000g of explosive shows less visible of grain boundaries, indicating the present of cold welding phenomena.

As a conclusion, as the amount of explosive increased, the pressing force increased which resulted to high hardness of specimen. The density of specimen increased with reduction of pores and increment of cold welding effects. Thus, specimen gain strength with better resistance to deformation after the pressing forces was applied.

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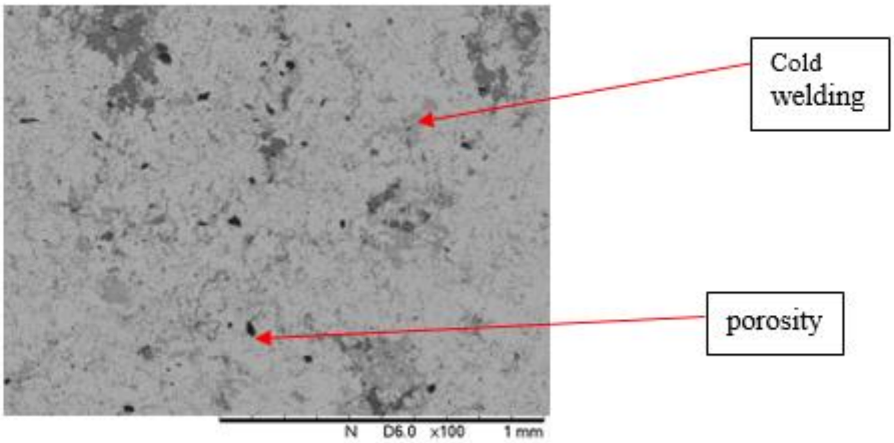

Figure 6. SEM microstructure of 500g of explosive

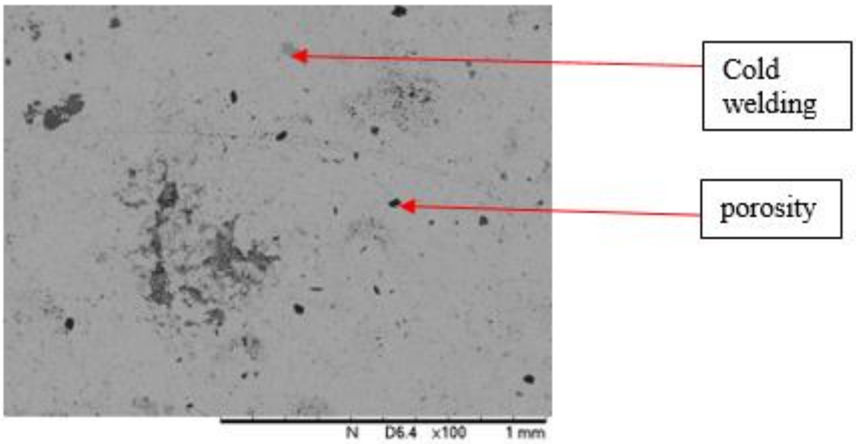

Figure 7. SEM microstructure of 750g of explosive

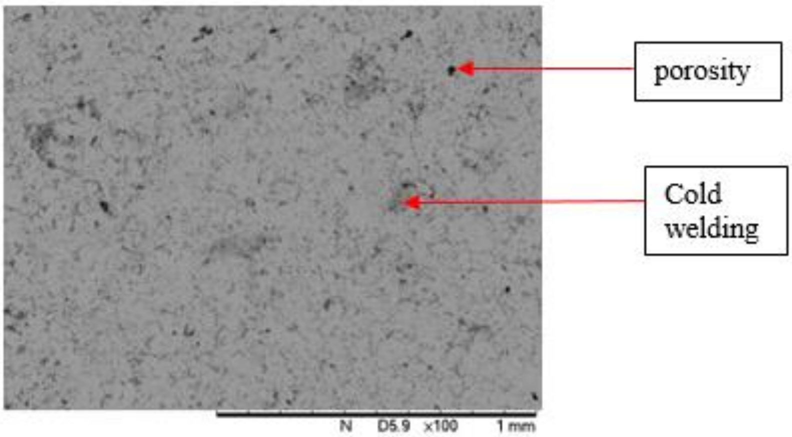

Figure 8. SEM microstructure of 1000g of explosive

3.3. Effect of explosive on Rockwell Hardness

Figure 9 shows the relationship between pressing force and the hardness of sintered specimen. From the graph, the hardness of sintered specimen increased proportianally with an increased in pressing force. The increasing of hardness shows a good result of compressibility of the Iron powder particles during pressing process (H. Li et al., 2014).

At 500grams of explosive, the hardness of sintered specimen was 45.8 HRA with pressing force 13292.252 tonne. When the explosive was increased to 750grams, the hardness of sintered specimen was increased to 46.7 HRA with pressing force 33377.738 tonne. The maximum hardness of sintered specimen was obtained for this experiment was 50.2 HRA at 1000grams of explosive and pressing force

33991.911 tonne. Figure 10 shows the graph of Hardness of sintered specimen vs Green densities of specimen. The increasing of hardness accompanied with an increase of pressing force is due to the increasing of density of specimen (Khan et al., 2013).
It can be concluded that, the higher the amount of explosive, the higher the hardness of Iron that formed due to its good compressibility of the powder particles during pressing. The increased in hardness accompanied with an increased in pressing force is to be attributed with the decreasing of porosity and increases in density (Khan et al., 2013). Besides, there is also some deformation in the compaction or pressing process that cause the hardness properties of the specimens increased.

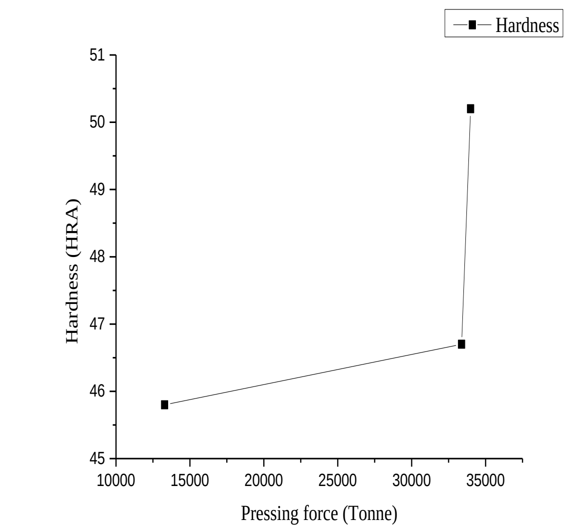

Figure 9. Graph of Hardness vs Pressing force

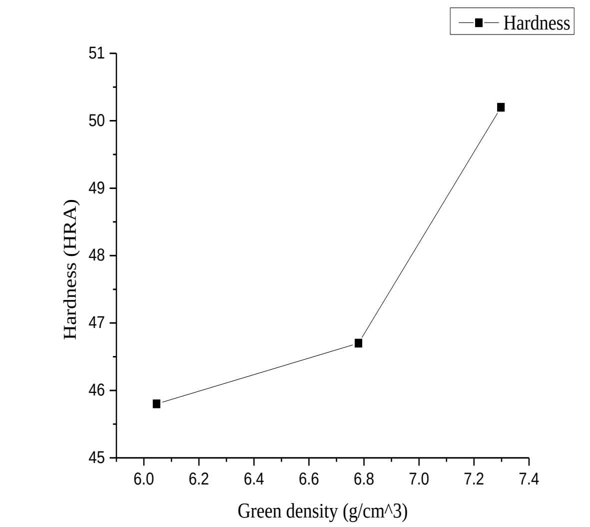

Figure 10. Graph of Hardness vs Green density

4. Conclusion

This research shows that it is possible to produce high density and high hardness of compact powder using Underground explosion. Since the results indicated the high density of compact powder which is $7.298 g/cm^3$, high hardness of compact powder which is $50.2 HRA$ at pressing force 33991.911 tonne and the SEM microstructure of compact powder shows the high quality bonding between the powder particles. Therefore, it can be concluded that, Underground explosion pressing is better to produce high quality of compact powder than conventional pressing.

5. References

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