



**Investigation on the Properties of iron Powder Subjected
to an Explosive Pressing using Emulsion Explosive
(Emulex)**

by

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LIST OF ABBREVIATIONS

ANFO	Ammonia Nitrate Fuel Oil
PETN	Pentaerythritol Tetranite
TNT	Trinitrotoluene
PE	Plastic Explosive
SEM	Scanning Electron Microscopy
TMD	Theoretical Maximum Density

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LIST OF SYMBOLS

v	Piston velocity,
P	Pressure applied,
M	Total mass of explosive apparatus,
F	Pressing force,
A	Area of specimen/plunger,
D	Diameter of specimen,
ρ	Density,
t	Thickness of specimen,
m	Mass of specimen,
v_d	Detonation velocity,
R	Explosive ratio
M_E	Mass of explosive
M_P	Mass of plunger
M_I	Mass of powder

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Penyelidikan Mengenai Sifat Serbuk Besi Terhadap Tekanan Letupan Menggunakan Letupan Emulsi (Emulex)

ABSTRAK

Kaedah metalurgi serbuk adalah salah satu teknik penting yang digunakan dalam industri untuk memampatkan serbuk ke logam pepejal. Untuk mencapai ketumpatan dan kekerasan maksimum dengan menggunakan teknik metalurgi serbuk, beberapa bahan tambahan seperti nikel dan serbuk aluminium atau pelincir digunakan untuk meningkatkan kebolehmampatan dan mengurangkan daya pelepasan, jadi sukar untuk mencapai kepadatan tinggi dan kekerasan tinggi dalam metalurgi serbuk menggunakan hanya satu jenis serbuk tanpa pelincir atau bahan lain. Masalah utama pemadatan serbuk adalah pembentukan retakan pada permukaan spesimen. Oleh itu, kaedah alternatif adalah dengan menggunakan penekan letupan. Tujuan penyelidikan ini adalah untuk mengkaji sifat-sifat serbuk besi yang dikenakan kaedah penekanan letupan dengan menggunakan bahan peledak emulsi (Emulex). Jenis bahan peledak yang digunakan adalah bahan peledak emulsi (Emulex) dengan berat cas 100 g, 250 g, 500 g, 750 g, 1000 g dan 1250 g dengan nisbah jisim letupan ke jisim penekan di tambah jisim serbuk 0.11, 0.27, 0.55, 0.82, 1.10 dan 1.38 masing-masing. Bahan peledak dibentuk menjadi bentuk cas untuk memberi tenaga yang lebih menekan. Letupan bawah tanah dilakukan kerana ruang terkurung dapat memberikan lebih banyak tenaga letupan. Serbuk besi tanpa pelincir atau bahan lain digunakan dalam penyelidikan ini. Kompak hijau disinter pada suhu 1000°C untuk mengukuhkan ikatan antara zarah. Ketumpatan padat besi dikira sebelum proses pensinteran. Analisis struktur mikro serbuk padat dilakukan dengan menggunakan mikroskop elektron imbasan (SEM). Kemudian, kekerasan serbuk padat diuji menggunakan Rockwell Digital Hardness. Hasilnya menunjukkan bahawa, besi padat sepenuhnya dan tidak ada pembentukan retak. Tidak ada pembentukan keretakan pada kompak hijau kerana tidak ditambahkan sebarang pelincir atau bahan lain dalam serbuk besi. Komposisi bahan yang tidak betul adalah salah satu penyebab pembentukan keretakan. Selain itu, penggunaan peledak emulsi (Emulex) dengan kecepatan peledakan 4500 m/s telah mengurangi pembentukan retakan kerana kecepatan peledakan rendah digunakan. Daya penekanan tertinggi yang diperoleh daripada eksperimen ini ialah 357.308k Tonne. Hasil ketumpatan maksimum teoritis untuk besi padat tanpa pelincir atau bahan lain menggunakan kaedah penekanan letupan adalah 94.40%, sementara hasil ketumpatan maksimum teoritis untuk penambahan aluminium dan serbuk besi menggunakan kaedah metalurgi serbuk adalah 94.55%. Kekerasan tertinggi yang diperoleh untuk besi padat ialah 50.3 HRA. Hasil struktur mikro menunjukkan keliangan yang lebih rendah dan terdapat kehadiran kimpalan sejuk dan fenomena saling mekanikal di permukaan spesimen kerana batas butiran kurang kelihatan. Penyelidikan ini menunjukkan bahawa mungkin untuk menghasilkan ketumpatan tinggi dan kekerasan tinggi serbuk padat menggunakan kaedah penekanan letupan. Ini menunjukkan bahawa, ketika nisbah letupan meningkat, daya tekan meningkat yang menyebabkan kekerasan tinggi dan kepadatan spesimen yang tinggi. Ketumpatan spesimen meningkat dengan penurunan liang dan pertumbuhan kesan pengelasan sejuk dan sifat mekanikal. Oleh itu, spesimen memperoleh kekuatan dengan daya tahan yang lebih baik terhadap ubah bentuk setelah daya tekan digunakan.

Investigation on the Properties of Iron Powder Subjected to an Explosive Pressing using Emulsion Explosive (Emulex)

ABSTRACT

Powder metallurgy method is one of the important techniques used in industry to compacted a powder to a solid metal. To achieve the maximum density and hardness by using powder metallurgy technique, some additive such as nickel and aluminium powder or lubricant are used to increase the compressibility and reduce the release force, so it is difficult to reach high density and high hardness in powder metallurgy using only one type of powder without any additive of lubricant or other material. The main problem of the compaction of powder is the formation of crack on the surface of specimen. Thus, an alternative method is by using explosive pressing. The aim of this research is to investigate the properties of iron powder subjected to an explosive pressing method using emulsion explosive (Emulex). The type of explosive used is emulsion explosive (Emulex) with charge weight of 100 g, 250 g, 500 g, 750 g, 1000 g and 1250 g with a mass ratio of explosive to mass of plunger add mass of powder of 0.11, 0.27, 0.55, 0.82, 1.10 and 1.38 respectively. The explosive is molded into shape charge to give more pressing energy. The underground explosion is conducted since confined space can give more blast energy. Iron powder without any additive of lubricant or other material is used in this research. Green compact is sintered at 1000°C to strengthen the bonding between particles. The density of iron compact is calculated before the sintering process. Analysis of compact powder microstructure is performed using scanning electron microscope (SEM). Then, hardness of compact powder is tested using Rockwell Digital Hardness. The result shows that, the iron compact is fully compact and there is no formation of crack. There is no formation of crack on green compact is due to non-added of any additive such as lubricant or other material in the iron powder. The improper material composition was one of the causes of formation of crack. Besides, the used of emulsion explosive (Emulex) with 4500 m/s detonation velocity had reduced the formation of crack because low detonation velocity is used. The highest pressing force obtained from this experiment is 357.308k Tonne. The theoretical maximum density result for iron compact without any additive of lubricant or other material using explosive pressing method is 94.40%, while the theoretical maximum density result for addition of aluminium and iron powder using powder metallurgy method is 94.55%. The highest hardness obtained for iron compact is 50.3 HRA. Microstructure results show lesser porosity and there are a presence of cold welding and mechanical interlocking phenomena at surface of specimens since the grain boundaries is less visible. This research shows that it is possible to produce high density and high hardness of compact powder using explosive pressing method. It shows that, as the explosive ratio increased, the pressing force increased which caused to high hardness and high density of specimen. The density of specimen increased with decrease of pores and growth of cold welding and mechanical properties effects. Thus, specimen gain strength with enhanced resistance to deformation after the pressing force was applied.

CHAPTER 1 : INTRODUCTION

1.1 Background of study

Iron powder is commonly used in powder metallurgy industry. Due to the increasing market in powder metallurgy industry and iron powder application, all manufacturer of iron powder is figuring out to expand their production capacity and develop the technical service facilities. Iron powder is commonly used in powder metallurgy industry because it is inexpensive compared to non-ferrous metal (Wang et al., 2009). Therefore, iron powder is not only limited to powder metallurgy industry, it also used in the manufacture of welding electrodes (Fallis, 1968).

For selection of metal powder, the metal type chosen for the research should have high strength and best characteristics. Mixtures of more than two metal can enhance the powder flow during die fill which is crucial aspect of the consolidation process and improves the mechanical properties of components. However, in this research, iron is the only type of metal used as a material without any additive of lubricant. Based on the previous analysis (Zhang et al., 2016), it is acknowledged that the iron powder exists in polygonal shape, not in circular shape as others. Due to the full attachment between each particle, iron can easily compact during the pressing process.

The aim of this research is to analyze the physical, mechanical properties and microstructure of iron when pressed using explosive pressing. To achieve that, pressing procedure will involve an explosive. An explosion is the sudden discharge of stored energy. The advantage of explosive pressing is that the energy is released as part of thermal radiation and it offers the good prospect of producing the high temperatures which is vital for a decent local metallurgical bonding at the powder particle interfaces. Tenaga Kimia Sdn Bhd in Rawang, the sole company in peninsular Malaysia that produces emulsion explosive (Emulex) which is the commercial grade explosive are the provider of explosive material used in this project. Explosive handling is supported by blast research unit from Universiti Pertahanan Nasional Malaysia (UPNM). The completion of iron compact produced by explosive pressing that will be examined in this project are density, hardness, and microstructure.

Apart from that, the target is also to investigate the pressing force of explosive pressing and for that purpose, the metal powder is pressed using the explosive pressing apparatus. Explosive can develop very high detonation pressure ranges from 1 GPa to 50 GPa resulting a high density of green compact. It is known that explosive compaction producing shock wave generated by detonation is convenient to compact the powder with a simple, low cost and promising approach. Furthermore, the crystalline grain had no enough time to growth because the duration time of explosive compaction to compact the powder was instantaneous (within microseconds).

The approach in this experiment is to produce iron metal with high density of green compact and high hardness using explosive pressing with different amount of commercial explosive. Explosive pressing of metal powders introduce a unique and exciting tool for the production of high density green compact. The advantages of

explosive compaction are short processing time and low-cost production. It is well known that, the pressure are greatly influences the achieve green strength, density and electrical resistivity of compacted metal powders. According to Geltman & Corp (1909), in such compaction, the pressure that are develop is 51,000 psi (0.35 GPa). In general, for best compaction, the pressure deliberately limited to 50,000 psi (0.344 GPa) to 60,000 psi (0.413 GPa).

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1.2 Problem statement

Powder metallurgy method is one of the important techniques used in industry to compacted a powder to a solid metal. To achieve the maximum density and hardness by using powder metallurgy technique, some additive such as nickel and aluminium powder or lubricant are used to increases the compressibility and reduces the release force, so it is difficult to reach high density and high hardness in powder metallurgy using only one type of powder without any additive of lubricant or other material. The highest theoretical maximum density of mixtures of aluminium and iron powder compacted using powder metallurgy method was 94.55% (Dhar et al., 2020).

According to Zohoor et al., (2006), study the explosive compaction of tungsten powder. This research only used one type of material which is tungsten without mixed with other material and using C4 as explosive material with 8092 m/s velocity of detonation. The highest density obtained was 18.6 g/cm^3 which was equal to 96% of tungsten theoretical maximum density and still cannot reach 100% of theoretical maximum density.

The main problem of the explosive compaction is the formation of crack due to a propagation of strong shock wave inside the material. Previous researchers Farinha et al., (2014) and Wang et al., (2016), reported that, there are present of microdefects such as formation of crack It is usually generated by tensile stresses and thermal residual stresses due to rapid cooling process after shock-loading.

1.3 Objective of study

The research objectives are:

- 1) To evaluate mass ratio of explosive to mass plunger and mass of powder on the pressing force, density and hardness of iron compact.
- 2) To evaluate microstructure of iron compact produced by using explosive pressing method.

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1.4 Scope of study

Referring to the research objectives, there are a few scopes of research due to some limitation in study area such as, the main study focuses on the properties of iron powder using explosive pressing method. The properties analysis of iron compact in this research include the density, hardness and the microstructure of iron compact.

This research is carried out at the blast testing field to press the iron powder using explosive pressing method. The blast testing had been done for three days in Kem Kongkoi, Jelevu, Negeri Sembilan. This experiment is supported by blast team from Universiti Pertahanan Malaysia (UPNM) for handling the explosive material. In this experiment, commercial explosive which is emulsion explosive (Emulex type 150) is used to press the iron powder becomes solid metal. The emulsion explosive is molded into conical shape charge. The amount of charge weight was limited from 100 g to 1250 g with mass ratio of explosive to mass plunger and mass of powder of 0.11, 0.27, 0.55, 0.82, 1.10 and 1.38 respectively. Besides, the metal powder that is used for this research is fine iron powder type (12310) from Sigma Aldrich, product of Sweden. In addition, there are no mixtures of metal powder or lubricant, iron is the only type of metal powder used in this research. The amount of iron powder for each specimen was 59.70 g. There are six number of specimens are produced from this experiment. The specimen diameter is limited to 51.50 mm to make it compatible with size of mould. This specimen had undergone sintering process which limited to 1000°C with heating rate 10°C/min

1.5 Significance of the research

This research will give advantages in manufacturing technology, especially in the development trend of powder metallurgy process. This application can be expanded in the industry with supported by blast research unit from Universiti Pertahanan Nasional Malaysia (UPNM) for explosive handling. Nowadays, it is difficult to reach high density and high hardness of product with low cost production and save in time. So, the alternative method to produce iron product with high density and high hardness is using explosive. Explosive pressing is an effective way to produce high density and high hardness of specimen since it used shock wave that produced by high detonation of explosive to press the powder material.

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CHAPTER 2 : LITERATURE REVIEW

2.1 Introduction

This chapter begins with a method of compaction which is explosive compaction. In this chapter the author also discussed about formation of crack from other researchers that using explosive compaction method, the important of mass ratio of explosive to mass of powder in explosive compaction, density of specimen, hardness and microstructure of specimen using explosive compaction method. Then, type of explosive that commonly used, such as Emulex, TNT and C4 and the properties of metal powder are provided in this section. Following with sintering process also discussed in this chapter.

2.2 Explosive compaction

Explosive compaction is a process to compact the powder, which produces high pressure and high temperature when the explosive is detonated (Li et al., 2002). This method is suitable for obtaining high densities in green compacts. The previous researcher reported that shock wave that generated from the detonation of explosive material can produce compact material with high quality within microseconds (Raming, et al., 2004; Zohoor et al., 2006). This technique is one of the unique characteristics, because of the very fast compaction within microsecond only, grain growth is not formed in the compacts after compaction process (Kim et al., 2011). Furthermore, explosive compaction can deliver a high magnitude impact load to the powder mass, thus, the densification is more effective (Lahiri & Bhargava, 2009). There are some major parameters controlling the explosive compaction such as the detonation velocity

of explosive material, the pressure of compaction and the ratio of the mass of explosive to the mass of powder (Zohoor et al., 2006).

There are two different methods for explosive compaction. The first method is known as a direct method where a thin wall of the container is filling with the metal powder and the end plugs are closed. Then, it was surrounded by a layer of explosive material as shown in Figure 2.1 (Buzyurkin et al., 2013). The other method of explosive compaction is an indirect method that involves of metal container submerged in water in closed containers. As shown in Figure 2.2, the indirect method of explosive compaction occurs in a presence of water tank (Zohoor & Mehdipoor, 2009). Table 2.1 shows some of the review of explosive compaction that was involved compaction of powder material. Most of the researcher used mixtures of powder to achieve maximum density and hardness of compact material. The highest theoretical maximum density achieve was 99.9% that used mixtures of tungsten and powder (Chen et al., 2018). The highest theoretical maximum density for explosive compaction that used only one type of material which was tungsten without any addictive was 96.7% (S. Wang et al., 2014; Zohoor et al., 2006).

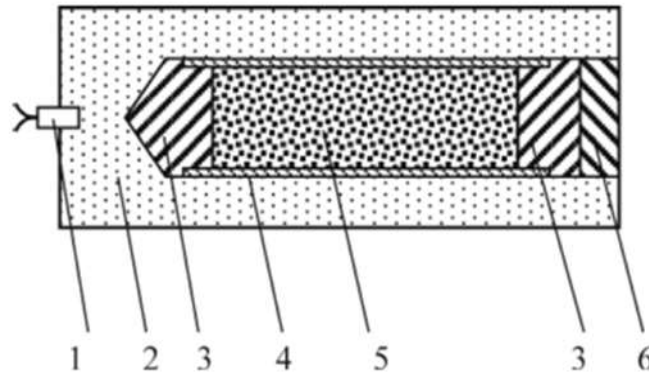


Figure 2.1: Direct method; 1-detonator, 2-explosive charge, 3-steel plugs, 4-container, 5-copper powder, 6-momentum trap
 Source: (Buzyurkin et al., 2013)

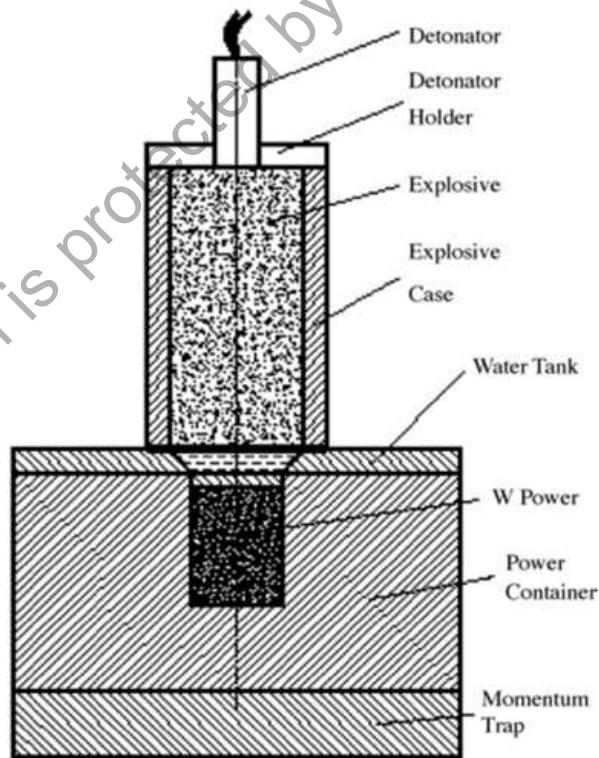


Figure 2.2: Indirect method
 Source: (Zohoor & Mehdipoor, 2009)

Table 2.1: Review of explosive compaction

No	Title	Author & Year	Explosive material	Detonation velocity (m/s)	Detonation Pressure (GPa)	Material of powder	Theoretical maximum density (%)	Hardness of specimen (HRA)	Mass ratio
1	Explosive Compaction of Metal Powder	(Mohammadi & Dravizeh, 2010)	RDX	8797	0.0361	copper	93.44	-	-
						steel	95.19	-	-
2	Explosive compaction of CuCr alloys	(Li et al., 2002)	Carbamide nitrate	3100	2.342	Mixed copper + ceramide	98.69	189 HB	1.338