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# Material Characterization of Follower Assembly of G5 155mm Gun Howitzer Breach Mechanism Block

(Pencirian Bahan Pengikutan Himpunan kepada Mekanisme Blok Pelanggaran Pistol Howitzer G5 155mm)

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ABSTRACT

*Medium alloy steel is widely used as a material for guns and rocket launchers due to its high strength and excellent machinability characteristics. The purpose of this study is to determine the material properties of the follower assembly used in a breech block gun launcher which is significantly important for the future product improvement. The microstructure and the effect of alloying elements in the follower assembly is evaluated in this study. The SPECTRO Optical Emission Spectroscopy (ES) method is used to analyse the chemical composition of the material and the Field Emission Scanning Electron Microscope coupled with Energy Dispersive X-Ray (FESEM-EDX) were used to analyse the inclusions of the sample. Results of the ES chemical composition analysis found that Nickel (Ni) is the major alloying elements beside Molybdenum (Mo), Chromium (Cr), Manganese (Mn), Silicon (Si), Sulphur (S), and Carbon (C) while chemical mapping and line scanning analysis of FESEM-EDX on inclusions distributed in the material microstructure identified as a compound of Manganese Sulphur(MnS). Fine dendritic microstructure arrangement and distribution in the microstructure analysis showed that the sample had been quenching in the heat treatment process, which also played a significant role in the material characterization. From the analysis, it is found that the material can be defined as medium alloy steel that is also typical for high strength material for ballistic application.*

*Keywords: Medium alloy steel; alloying effect; microstructure; mechanical strength*

ABSTRAK

*Keluli aloi sederhana banyak digunakan sebagai bahan untuk pelancar senjata dan roket kerana kekuatannya yang tinggi dan ciri-ciri kebolehmesinan yang sangat baik. Tujuan kajian ini adalah untuk mengetahui sifat bahan susunan pengikut follower assembly yang digunakan dalam peluncur breech block gun yang sangat penting untuk peningkatan produk di masa hadapan. Struktur mikro dan kesan pengaloian unsur utama dalam pemasangan pengikut dinilai dalam kajian ini. Kaedah SPECTRO Optical Emission Spectroscopy (ES) digunakan untuk menganalisis komposisi kimia bahan dan Mikroskop Elektron Pengimbasan Pelepasan Medan yang digabungkan dengan X-Ray Energy Dispersive (FESEM-EDX) digunakan untuk menganalisis kemasukan sampel. Hasil analisis komposisi kimia ES mendapati bahawa Nikel (Ni) adalah unsur paduan utama di samping Molibdenum (Mo), Kromium (Cr), Mangan (Mn), Silikon (Si), Sulfur (S), dan Karbon (C) sementara pemetaan kimia dan analisis imbasan garis FESEM-EDX mengenai kemasukan yang diedarkan dalam struktur mikro bahan yang dikenalpasti sebagai sebatian Sulfur Mangan (MnS). Susunan dan taburan struktur mikrodendritik menunjukkan bahawa sampel telah melalui proses rawatan panas secara lindap kejut yang sempurna, yang juga memainkan peranan penting bagi pencirian bahan. Dari analisis, didapati bahawa bahan tersebut dapat dikaetogarikan sebagai keluli aloi sederhana berkekuatan tinggi yang biasa digunakan dalam aplikasi balistik.*

*Kata kunci: Keluli aloi sederhana; kesan aloi; struktur mikro; kekuatan mekanikal*

## INTRODUCTION

Material characterization study of the follower assembly of the G5 MK III Howitzer 155 mm breech block is extremely significant due to its application. Gun firing resulting in combustion and explosion of the charge back and the mechanical action in the gas pressure in the chamber system produced is approximately between 14 Mpa to 16 Mpa. A study on the Howitzer by Wu et al. (2008) demonstrated that during firing, large amounts of heat flow into the gun bore surfaces and results in wear and erosion of the gun bore. Moreover, the chamber surface temperature will reach the cook-off temperature of the propellant during long, sustained firing, which will have an adverse effect on user safety and facilities.

Due to the high pressure and high stress involved during gun firing, the component must be made from appropriate material that can withstand the stress and have an excellent blast resistance. Before the fabrication of the geometry of barrel, the material for the fabrication has to be selected for the analysis of the barrel design. Normally there are two materials that are mainly used for the fabrication of the barrel. The first is AISI 4140 because of its ability to withstand the (360 MPa to 560 MPa) pressure ranges of the explosive and because of its low cost (Dixit et al. 2016). Another material that is usually used as gun chamber is AISI 4340 alloy steel. It is heat-treatable and is a low alloy steel containing chromium (Cr), nickel (Ni), and molybdenum (Mo). Alloying material such as molybdenum prevents the steel from being susceptible to temper embrittlement (Shivaprakash et al. 2015). The presence of nickel in steel could increase the impact strength, toughness, improving corrosion resistance, and low thermal expansion coefficient at lower temperatures (El-Sayed et al. 2017).

The wide range of mechanical properties of the steel can be obtained through alloying addition, mechanical working or by microstructure manipulation (Bhadeshia 2001). In order to increase steel hardenability and to act as binate stabilizers, silicon, molybdenum, and chromium are added as alloying elements. An optimum combination of mechanical properties can therefore be obtained in steels by the development of dual phase microstructures (Kumar et al. 2008; Tomita & Okabayashi 1985). Development of ferrite-martensitic in steels have shown much better combination of strength, toughness and ductility as compared to full martensitic structure due to strain hardening of ferrite in the vicinity of martensitic (Saeidi & Ekrami 2009).

## MATERIAL & METHODOLOGY

The Gun – Howitzer Medium Towed 155 mm used for general support fire power during the battle in Malaysian Army. Entering and procurement in 2002 from South Africa. Follower functions are to assist the movement of the trigger mechanism, and as a safety lock to the trigger mechanism. The method used for determining material characteristic is through the hardness test, metallographic examination, and chemical composition analysis.

### METALLOGRAPHIC EXAMINATION

For the metallographic examination, the sample was sectioned across the follower assembly as shown in the dotted box in Figure 1, and the portion of the samples was mounted with the Bakelite powder using LEICO hot press mounting. A cured specimen was then grinded using silicon carbide paper with grit sizes of 240, 400, 800, and 1 000 to minimize the surface scratches. The ground specimen was then polished using an appropriate non-metal polishing cloth together with a diamond paste (grit size of 6 µm to 1 µm) to produce mirror-like surface. A cleaned and dried polished specimen than was etched with 2% Nital reagent for about five seconds to reveal the microstructure for the examination.

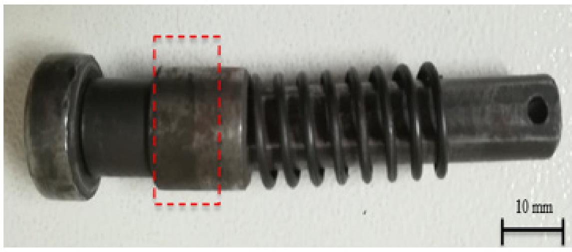


FIGURE 1. The dotted mark indicates location for metallographic examination of the follower assembly

### HARDNESS TEST

A Shimadzu Micro Vickers Hardness test equipment was used to measure the hardness value of the sample. A polished specimen was placed on the hardness testing fixture. Macro-indentation was made on the surface of the specimen by applying 1 000 gf for 15 seconds and the average results taken at five different locations are presented in the next topic of result and discussion.

### CHEMICAL COMPOSITION ANALYSIS

A SPECTRO Optical Emission Spectroscopy equipment was used to analyse the chemical composition of the follower assembly. The prepared sample material was vaporized with the testing probe by an arc spark discharge. The atoms and ions contained in the atomic vapor are excited into emission of radiation. The radiation emitted is passed to the spectrometer (arc spark OES) optics directly or via an optical fibre, where it is dispersed into its spectral components. From the range of wavelengths emitted by each element, the most suitable line for the application is measured by means of a CCD or PMT. The radiation intensity, which is proportional to the concentration of the element in the sample, is recalculated internally from a stored set of calibration curves and can be shown directly as percent concentration.

## FESEM-EDX ANALYSIS

The Thermo Scientific APREO field emission scanning electron microscope (FESEM) coupled with the Oxford AZTEC Energy Dispersive X-Ray Spectroscopy (EDX) is a combination tool of a live electron image with live X-ray chemical imaging used to determine the chemical composition of the follower assembly. Mapping analysis and line scan method were used to determine the inclusion chemical composition. For the metallographic examination, the sample was sectioned.

## RESULT & DISCUSSION

### MICROSTRUCTURE ANALYSIS

Figure 2 shows the micrograph of martensitic microstructure of the follower assembly in carbon steels that experienced the quenching process (rapid cooling rate) similar microstructure was observed by (Li et al. 2007; Sumi & Malathy 2013).The martensitic microstructure formation also has been discussed by several researchers in their studies (Li et al. 2007; Rafa & Tolouei 2014;Alabi et al. 2012).

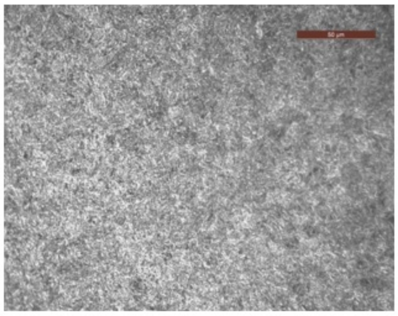

FIGURE 2. Micrograph of martensitic microstructure of the follower assembly

The face-cantered cubic (FCC) austenite had transformed to a highly strained body-cantered tetragonal (BCT) to form a needle-like microstructure (martensitic) that is supersaturated with carbon that strengthens the material. The micrograph also revealed the metallic inclusions were evenly distributed to indicate the proper heat treatment experienced by the sample in the fabrication process.

### HARDNESS TEST

The average micro hardness test result is 381 HV (39 HRC) as shown in Table 1. This result is typical for low alloy steel 4000 series

TABLE 1. Result of hardness test

| Statistic | Force, gf | D1 | D2 | Hardness HV | Hardness HRC |
|---|---|---|---|---|---|
| Minimum | 1000 | 69.39 | 69.39 | 379.89 | 38.81 |
| Maximum | 1000 | 70.34 | 69.86 | 382.49 | 39.17 |
| Mean | 1000 | 69.67 | 69.77 | 381.45 | 39.06 |
| Std.Dev | 0 | 0.42 | 0.21 | 1.42 | 0.14 |
| Variance | 0 | 0.18 | 0.04 | 2.02 | 0.01 |

### CHEMICAL COMPOSITION ANALYSIS

As shown in Table 2, the chemical composition analysis result of the follower assembly are compared between the 4130 and 4340 steels. This comparison was made based on its application and other similarity in material properties like high strength, high abrasion, and fatigue resistance. Comparison of the three metals show that the percentage of chemical composition are quite similar except the nickel, which is slightly higher for the follower assembly, while molybdenum is slightly lower

TABLE 2. Chemical composition analysis results

| | G5 Follower | 4130 | 4340 |
|---|---|---|---|
| Sulphur, S | 0.0095 | 0.0113 | 0.04 |
| Silicon, Si | 0.263 | 0.245 | 0.15-0.35 |
| Carbon, C | 0.298 | 0.303 | 0.37-0.47 |
| Chromium, Cr | 1.18 | 0.924 | 0.7-0.9 |
| Manganese, Mn | 0.590 | 0.541 | 0.6-0.8 |
| Molybdenum, Mo | 0.0443 | 0.168 | 0.2-0.3 |
| Nickel, Ni | 4.22 | 0.088 | 1.65-2.0 |
| Phosphorus, P | 0.0005 | 0.0105 | 0.035 |

## FESEM-EDX ANALYSIS

The mapping analysis of the follower assembly microstructure shows the black dots inclusion with the size varying approximately 0.5-1.0 micron as shown in Figure 3. The inclusion then was elemental identified as Sulphur (light blue colour) and manganese (yellow colour). These two elements were overlapping each other. While, in the line scan analysis (Figure 4) showed the peaks of manganese and sulphur observed to have similar intensity to evidence that the black dots are the manganese sulphur (MnS) inclusion. The formation of MnS inclusions during solidification influences the mechanical properties and machinability of the steel (Jianxun et al. 2019).For the metallographic examination, the sample was sectioned.

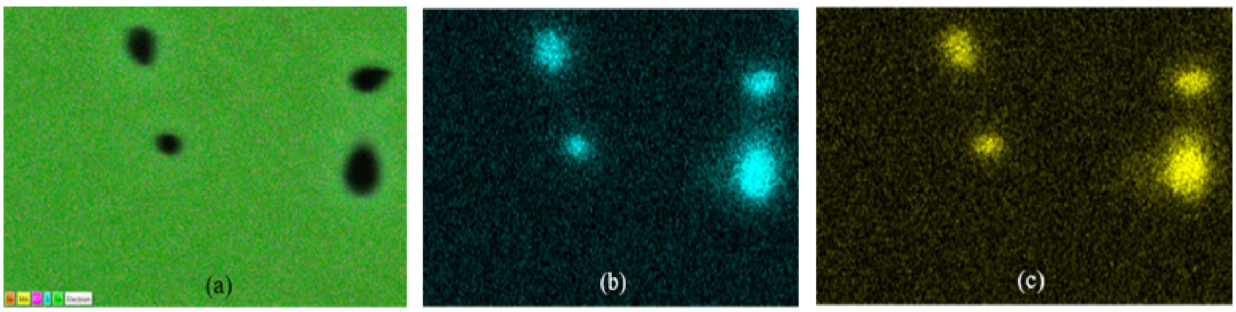


FIGURE 3. Mapping image showing the inclusion of the follower assembly (a). The inclusion elemental identified as sulphur (b) and manganese (c)

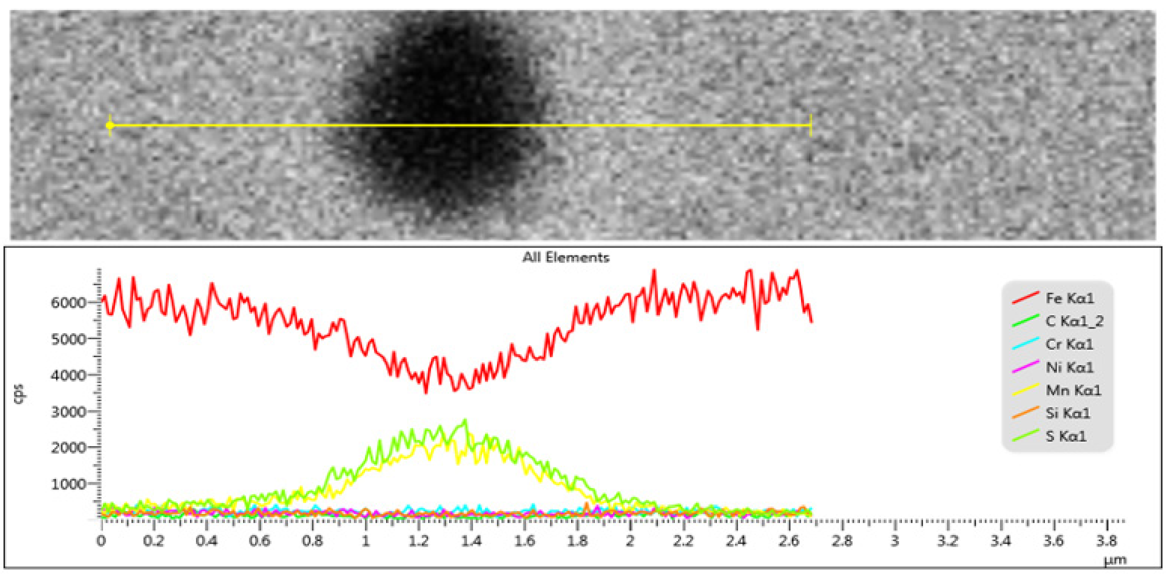


FIGURE 4. The selected inclusion analysed using line scan method showed the peaks of manganese and sulphur observed to have similar intensity

## CONCLUSION

Based on the results of the material characterization, the following conclusions are drawn. The chemical composition of the samples indicate that the material of the follower assembly is made from the AISI 4000 series grade and the nearest is AISI 4340 Steel typical for high strength material for ballistic application. The microstructure examination of the samples revealed the martensitic structure and was confirmed by the hardness measurement of the specimen indicated the characteristic of high strength alloy steel. Other than that, the influence of alloying elements and intermetallic inclusion distribution in the microstructure analysis has played a significant effect to the material characterization. The MnS inclusion detected in the steel microstructure is an additional value to strengthen the steel. Last but not least, from the material characterization, further study could be conducted in terms of material selection for the design improvement process.

### DECLARATION OF COMPETING INTEREST

None

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