Experimental Investigation on the Ballistic Resistance of Aluminium Plate under High Velocity Impact

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ABSTRACT

Ballistic resistance has become towards researchers' attention especially those in enforcement industry. In the ballistic resistance, researchers are keen to determine the lowest velocity of projectile that able to perforate a target. From result obtained, researchers can propose modification to enhance the survival of enforcement personnel. For an example, armor shield which is employed by enforcement personnel during gun fight. The main objective of this paper was to present the preliminary result of ballistic resistance of aluminium plate that will be used as a reference in the experiment works later. Future works will involve aluminium laminated with z-composite. In this study, the target was aluminium plate with thickness of 3 mm and fragment simulating projectile (FSP) acted as the projectile. The FSP was launched from gas gun which was located 2 meters from the aluminium plate. The velocity of FSP was varied by changing the charge weight. The experiment was carried-out at Science and Technology Research Institute for Defence (STRIDE), Batu Arang. From the experiment conducted, it was found the ballistic limit was equal to 257.7 m/s. Furthermore, there were two main modes of failure observed which were non-perforation and successful perforation. For non-perforation, the mode of failure was crater with and without FSP embedded into the plate. Meanwhile for the successful perforation, the mode of failure was a hole along with petals.

Keywords: *Ballistic Resistance, Aluminium Plate, Fragment Simulating Projectile (FSP), High Velocity Impact, Modes of Failure*

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Introduction

Nowadays, many researchers are keen on ballistic resistance study. One of main contribution of ballistic resistance study is developing armor shield. Enforcement force such as soldier and police required good armor shield when they are on duty. Their life is on stake when dealing with terrorist. The armor shield supposed to withstand the armour piercing (AP) and has light weight to ease movement.

Ballistic limit (BL) is defined as the initial velocity of projectile that has chance 50% to perforate the target [1]. BL phenomenon involve several types of failure modes. Once the initial velocity exceeded the BL, the residue velocity become attention to researchers. Then, researchers correlated the initial velocity of projectile with the residue velocity of projectile in their works [2]. Furthermore, researchers also considered the energy absorbed by the target to see the effects towards thickness of target, thickness of laminate, projectile’s initial velocity, size and shape.

In ballistic study, there are many types of target used by researchers. Common targets are composite, ceramics and plate. Composite was made from Kevlar® fabric and polypropylene (PP) matrix [3], Glass Laminate Aluminum Reinforced Epoxy (GLARE) [4], plates of tungsten carbide (WC), ceramic balls or steel balls embedded in a polymer matrix [5], shell aramid [6], knitted fabrics [7] and woven kenaf–Kevlar [8]. Ceramics has been used by researchers like [9] and [10] in their works. In [10] works, the ceramics was coupled with aluminium plate. Meanwhile plate such as aluminium ([2] and [11], ultra-high hardness armour steel (UHA) [12], ultra-high-molecular-weight polyethylene (UHMWPE) [13] and armour panel [14] have became among the choice target.

To achieve the objective of study, each researcher has their own preference on type of projectile. Basically, it is choosen based on type of target. Among projectile employed in ballistic study were 5.56 mm, 7.62 mm and 9 mm live bullet [3, 5, 9, 12], fragment simulating projectile [2, 6, 8, 12], flat and conical nose projectiles [4], ogive and blunt nosed projectiles [11], and spherical projectile [7, 13].

This paper intends to present the preliminary result of ballistic resistance for aluminium plate. This result will be used as a reference for future work which will involve aluminium plate laminated with z-composite.

Test Set-Up

Figure 1 and Figure 2 show the actual picture of test set-up and schematic drawing of test set-up, respectively. Chronograph was placed in between the gas gun and aluminium plate to capture the initial velocity of fragment simulating projectile (FSP). The distance between the gas gun and aluminium plate was 2 meter. The complete 7.62 mm live bullet is shown in Figure 3(a). The head of live bullet was taken out to be replaced with sabot and FSP. The FSP was attached to sabot which snugly fit to jacket of 7.62 mm bullet as shown in Figure 3(b). Figure 3(c) and 3(d) show the sabot and FSP, respectively.

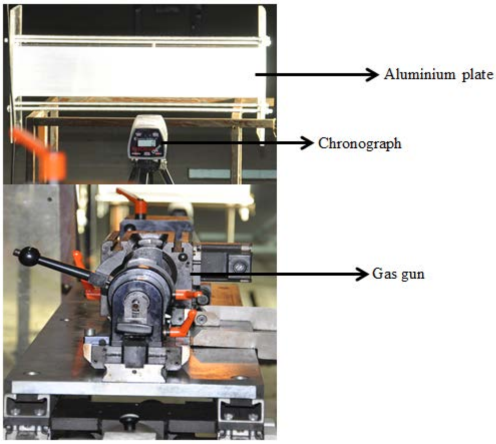


Figure 1: Actual picture of test set-up

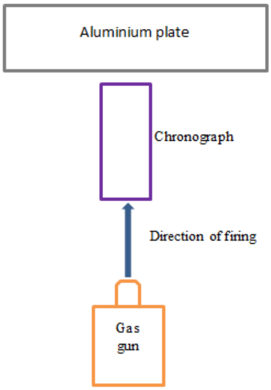


Figure 2: Schematic drawing of test set-up

(a) (b) (c) (d)

(a) Complete 7.62 mm live bullet
(b) Complete projectile
(c) Sabot
(d) Fragment simulating projectile (FSP)

Figure 3: The arrangement of projectile

Methodology

In this study, the pre-test was conducted before the actual test conducted. During the pre-test, the live bullet 7.62 mm was employed to strike bull's eye. The velocity of live bullet must achieve at least 800 m/s. Once these two conditions were fulfilled, the actual test took place. In the actual test, the velocity of FSP was set to achieve the non-perforation case, followed by complete perforation. Any test need to be repeated if the required result was not achieved. The velocity of FSP was increased by adding more charge weight in the bullet's jacket. All velocities were recorded to determine the ballistic limit. The test end when the complete perforation achieved. Figure 4 shows the methodology flow-chart for this study.

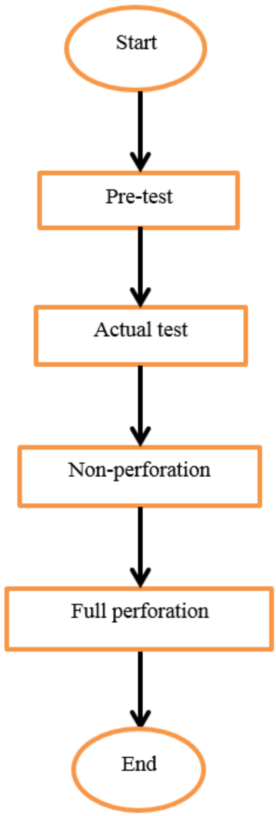
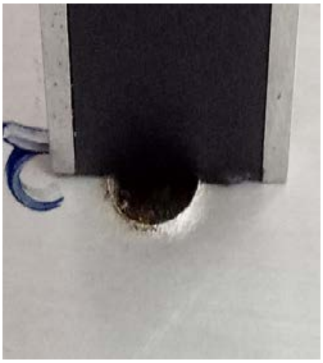


Figure 4: Methodology flow-chart

On top of ballistic limit, depth of perforation (DOP) and depth of crater (DOC) were measured on the front and rear plate, respectively. It was measured by using digital caliper. Figure 5 shows how the measurement was carried-out. The digital caliper was set to zero on the plate as shown in Figure 5(a). Then, for non-perforated case, the depth of probe was inserted into the crater to measure the DOP as shown in Figure 5(b). Next, Figure 5(c) shows the depth of probe measure the height of FSP embedded into the plate to measure the DOC. Furthermore, for successful perforation, Figure 5(d) shows the measurement of DOC by measuring the highest petal.

(a) Setting datum



(b) Measuring the depth of crater

(c) Measuring the height of embedded FSP

(d) Measuring the highest petal

Figure 5: Measurement of DOC and DOP

Result and Discussion

Ballistic Limit

Table 1 tabulates the initial velocity of FSP and the perforation condition after impacted the aluminium plate. There were only 6 tests were tabulated to represent the highest velocity failed to perforate and the lowest velocity successfully perforated the aluminium target. By taking an average [15], the calculated ballistic limit was equal to 257.7 m/s. It means that when the FSP had the initial velocity of 257.7 m/s, it had 50% chance to perforate and 50% chance not to perforate the aluminium plate.

Table 1: FSP's Initial Velocity and Perforation

Test	Initial Velocity (m/s)	Perforation
1	239	No Perforation
2	248	No Perforation
3	253	No Perforation
4	265	Perforated
5	268	Perforated
6	273	Perforated

Modes of Failure

Table 2 tabulates the modes of failures for both non-perforated and perforated cases. For non-perforated case, there were two modes of failure which were crater developed without FSP embedded into the plate and crater developed with FSP embedded into the plate. The FSP with initial velocity of 221 m/s to 239 m/s had lost its momentum before the impact. This has caused the FSP to impact the front plate with slant position as shown in Figure 5. Unfortunately, after the impact incident, the FSP did not embed into the wall due to the depth of perforation was shallow. Nevertheless, the depth of perforation (DOP) became deeper and the depth of crater (DOC) became higher as the initial velocity increased. Figure 6 show the rear view of plate after impacted by FSP with initial velocity of 239 m/s. Observed that there was a crack at some portion of the plate as shown in Figure 6(a).

Then, when the initial velocities of FSP was 248 m/s and 253 m/s, the crater developed with FSP embedded into the plate. But, the DOP was shallower compared with previous initial velocity. It was because when the FSP embedded into the plate, the DOC was blocked by FSP as shown in Figure 7. Thus, it was impossible to measure the actual DOP. That's the reason why value of DOP decreased. However, the DOC still increased which made this observation valid. Figure 8 show the condition of FSP after impacted the plate with initial velocities of 248 m/s and 253 m/s. It can be seen from the rear plate, the crater developed is deeper.

Meanwhile for the FSP that successfully perforated the plate, there was a hole developed with petals. These petals were created due to high radial and circumferential stresses. It is common phenomenon observed in ballistic test when metallic plate like aluminium experienced a localized high intensity loading [16]. Figure 9 shows the hole created on the plate after impacted by FSP with initial velocity of 265 m/s. Then, Figure 10(a) and 10(b) show the petals developed on the rear plate after impacted by FSP with initial velocity of 268 m/s and 273 m/s, respectively.

Table 2: FSP's Initial Velocity and Modes of Failure

Test	Initial Velocity (m/s)	Modes of Failure		
		Wall Deformation	DOP (mm)	DOC (mm)
1	221	Crater without FSP embedded	2.23	0.99
2	237	Crater without FSP embedded	2.86	1.81
3	239	Crater without FSP embedded	3.75	2.80
4	248	Crater with FSP embedded	0.60	3.65
5	253	Crater with FSP embedded	1.43	4.36
6	265	Hole with petals	Nil	1.19
7	268	Hole with petals	Nil	1.30
8	273	Hole with petals	Nil	1.33
9	299	Hole with petals	Nil	1.35
10	322	Hole with petals	Nil	1.43

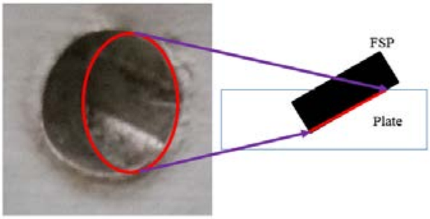


Figure 5: The crater developed after impacted by FSP with initial velocity of 237 m/s

(a) Rear view of crater

(b) Side view of crater

Figure 6: Rear and side view of crater after impacted by FSP with initial velocity of 239 m/s

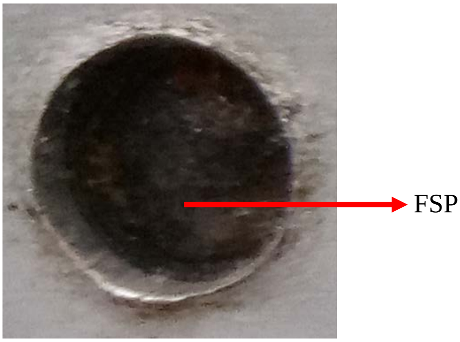


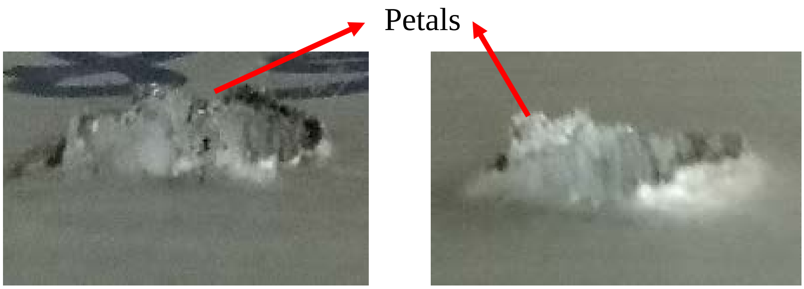
Figure 7: The FSP embedded into the plate (front view of plate)

(a) Initial velocity = 248 m/s

(b) Initial velocity = 253 m/s

Figure 8: The FSP embedded into the plate (side view of FSP)

Figure 9: Hole developed on the plate after successful perforation



(a) Petals caused by 268 m/s (b) Petals caused by 273 m/s

Figure 10: Petals developed on the rear plate

For the case FSP successfully perforated the plate, there was no DOP measured due to hole was developed on the plate. Then, the DOC of this case was increased from initial velocity of 265 m/s up to 322 m/s. However, the value of DOC was lower than the non-perforated case. It was due for the non-perforated case, the DOC was measured from the rear plate to the highest point of FSP embedded. Meanwhile for the successful perforation, the DOC was measured from the rear plate to the highest point of petals.

Figure 11 shows the correlation between the initial velocity of FSP and DOC for both cases i.e. non-perforation and successful perforation. Both correlations were best represented by the linear correlation. This observation was agreed with [17] works. Equation (1) and (2) stated the correlation of initial velocity and DOC for non-perforated and successful perforated, respectively. It can be seen from the Figure 12, the steep gradient is observed for non-perforated case. But, for the perforated case, the gradient is insignificant. It was due to the way of DOC measured as mentioned earlier. For the perforated case, the DOC was measured to the highest petal. Meanwhile for the non-perforated case, the DOC was measured to the highest point FSP embedded since petal was intact to FSP. It was quite difficult to get correct reading of the highest petal by using digital caliper.

$$DOC = 0.11\ (\text{Initial Velocity}) - 22.81 \tag{1}$$
$$DOC = 0.003\ (\text{Initial Velocity}) + 0.45 \tag{2}$$

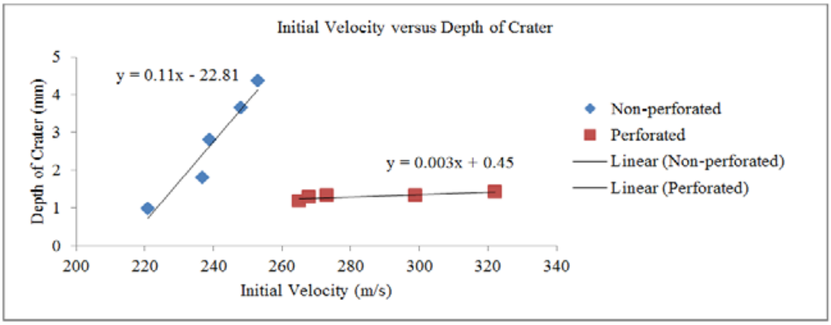


Figure 11: Correlation between the initial velocity and depth of crater for both cases

Conclusion

The ballistic limit for aluminium plate which was impacted by fragment simulating projectile (FSP) was 257.7 m/s. There were two main modes of failures observed, namely non-perforated and successful perforation. The depth of crater (DOC) was correlated with initial velocity of FSP linearly which showed the same agreement by previous researcher.

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