Journal of Engineering Research & Education
Vol. 3, 2006 (70-75)

The Behavior of Projectile Ricochet Off Various Wooden Targets

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Received : 14 January 2006 / Accepted : 22 November 2006
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ABSTRACT

This paper details the assessment of bullet ricochet as a function of incident angle and the impact plate material. A series of experimental testing have been carried out on three different woods chosen to give range of hardness, ranked from the hardest to the softest. Each wood was fired upon at varying angles of incidence until ricochet was observed. The tests were conducted in an indoor short range using a standard 0.22 calibre bolt-action rifle. In general, the ricochet angle was found to increase with an increase in angle of incidence but decrease with an increase in target hardness.

INTRODUCTION

The experiment is conducted to study the phenomenon of projectile ricochet off wooden targets. The purpose is to study the effects of wooden hardness on the phenomenon of ricochet. It is to be achieved by studying the experimental data found when firing bullets onto three types of wooden targets varying in hardness at various angles of incidence. The term 'ricochet' can be defined in many ways. A paper by Mohan Jauhari [1] gives a definition of ricochet as being "when a bullet strikes a target of sufficient solidarity at low angle it may, while maintaining its integrity, be deflected from its original path as a result of impact and travel in a direction quite different from its original one. Such a deflection of a bullet constitutes a true ricochet". Ricochet is likely to occur when a high speed projectile approaches the target material at low angle and cause the projectile to rebound off or penetrate but re-emerge from the same surface. The study of this branch of projectiles is also known as ballistics engineering [2].

The study of ricochet phenomenon has many applications. Most notably, it is used in the field of criminal forensics and also in disaster analysis. A trained scientist could use the knowledge in ricochet phenomenon, to study a hole or mark left on a material and calculate the velocity of the projectile and collision angle, thus figure out who is responsible and how's the incidents took place. The knowledge of this phenomenon is also applied in designing shooting range, protective clothing, and drawing up safety precaution. Since wood used in the experiment is a natural composite material, the data can also be used for evaluation of new composites to generates new generation of material composites [3].

Previous investigation conducted in the field of forensic ballistics shows that, the phenomenon of ricochet is not very well understood even amongst the experts in the field. Literature review conducted prior to the project shows lack of data concerning critical angle for ricochet particularly upon the impact on wooden target.

Forensics experts, Jauhari [1] defined the critical angle for ricochet as "the maximum angle of incidence at which the bullet ricochets". He goes on to say that once the angle of incidence exceeds this value, the bullet fails to ricochet by either disintegrating or penetrating the target. Jauhari also mentioned in his findings that, the angle of ricochet is less than the angle of incidence. However, work by Bell [4] on wooden target suggested that, the angle of ricochet was actually larger than the angle of incidence. Paper by W. Johnson and S.R. Reid [5] on the other hand, suggested that, the critical angle for ricochet, θ_c can be represented by the expression:-

$$\theta_c = \sqrt{\frac{\rho}{\rho'}} \qquad (1)$$

Where ρ, is the target material density
ρ' is the projectile material density.

However, according to Jauhari [1] and Bell [4], the equation does not hold since the critical angle was found to be dependent on different various factors including projectile velocity, target hardness, etc. We can conclude that, from prior studies, there were also no clear definitions regarding the relationship between the angle of incidence and the angle of ricochet.

EXPERIMENTAL METHODOLOGY

The experiment was carried out by firing a bullet onto wooden target at various angles of incidence until ricochet was observed. This investigation is not only expected to help in understanding the phenomenon of bullet ricochet off wooden target but also to provide some useful data that can be used to define the relation of ricochet angle to the angle of incidence and target hardness.

The set up for this experiment consist of a standard. 22 calibre bolt-action rifle securely mounted at its two ends on a stable bench. A chronoscope was placed right at the end of the rifle's barrel to record the initial velocity of the projectile upon leaving the rifle. At the other end of the bench, a table is used to house the wood samples, chronoscope and a backstop. The alignment of the riffle was calibrated and a line was marked on the table to show the path of the bullet by using the laser pen. Accurate measurement of the angle of incident was also marked on the table by using a level protractor. A frame of iron angle fixed to heavy metal base was used to hold the target material and prevent it from moving when struck by the projectile. In order to establish the angle of ricochet, backstop was placed at an angle to the target material to capture the bullet after ricocheting. The path of the ricocheted projectile was noted by a hole left in the backstop. The full arrangements can be seen in Figure 1.

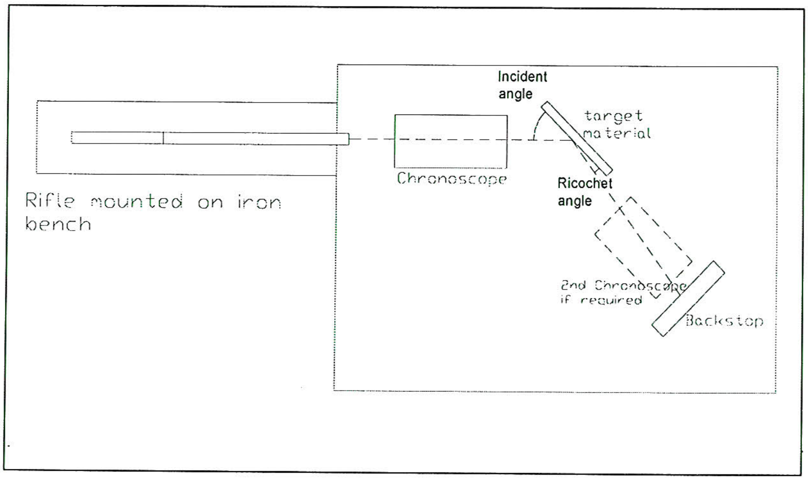

Figure 1. Experimental arrangement for the firing test conducted in this project.

In order to investigate the effects of target hardness on ricochet behaviors, three types of wood were used; Jelutong, Pine and Sapele, with Jelutong the softest target, Pine with the medium hardness and Sapele the hardest of all [3]. It is also important to ensure that all the samples were sawn from single trees/planks to minimise any inconsistencies of the target material properties. The wood samples should be cleared from obvious imperfection such as knots, crack, splits, etc. Target specimens were cut and secured onto the iron frame holder by using an adjustable clamp. The specimen is then placed at the angle of incidence for the bullet to give the desired projectile trajectory.

In this investigation, spherical projectile of 5mm in diameter was used as ammunition to eliminate any geometrical effects upon the impact on wooden targets. By using spherical projectiles, the influence of the bullet profile was minimized regardless of the angle of contact. It should be noted that, these type of cartridge will left a residue inside the rifle's barrel upon firing and caused a clog that reduced the projectile velocity. It is therefore to make sure that the barrel is clean each time the firing test was conducted.

After each shot, the condition of the specimen was examined to identify the Mode of Impact. The projectile is then extracted from the backstop and the velocity reading was noted. If ricochet had occurred, the angles of ricochet □, was calculated by means of simple trigonometry. The horizontal distance, d_1 where the bullet left the target and hit the backstop was measured as well as the vertical distance, d_2 between the target plate and the hole mark left on the backstop. These measurements were then used in the calculation of the angle of ricochet, where

$$\text{Ricochet Angle, } \varphi = \tan^{-1} \quad (2)$$

RESULTS AND DISCUSSION

The studies has categorized the projectile impact into four different modes: - perforation, capture, ricochet and fragmentation [6]. These four characteristics were then used to identify the mode of impact observed in the test. Results from this investigation is represented in Figure 2. It shows that an increase in angles of incidence causes an increment in ricochet angle. It is fairly to say in general that, the angle of ricochet is directly proportional to the projectile incident angle regardless of the target hardness. The result also shows that, ricochet angles are normally larger than the angles of incidence. At high incident angle, the projectile is more likely to penetrate or to be captured by the target material. As the projectile incident angle was lowered, the projectile would either enter and embedded inside the target material or enter the target and re-emerged from the same surface creating a groove. This is then followed with full body ricochet at lowest angles of incidence. It was found out that, full body ricochet tends to occur at very low incident angles, between 5° to 20° roughly.

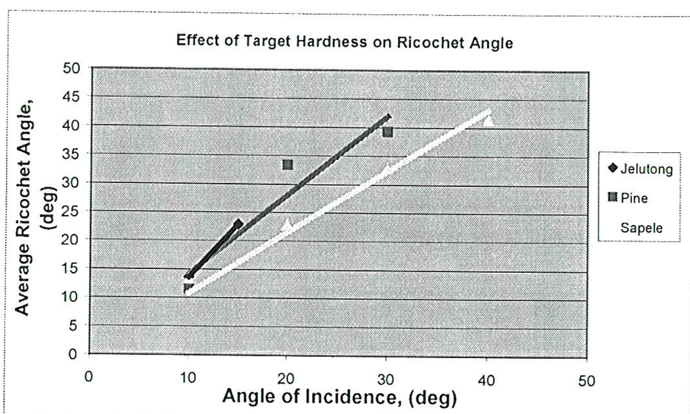

Figure 2. Relationship between Ricochet Angle and Incident Angle after an impact on 3 types of wooden targets.

Figures 2, shows the ricochet angle for three types of target material; Jelutong, Pine and Sapele. Clearly then, the target material has a large effect on ricochet behavior. Experimental results suggest that the harder the target material, the lower the ricochet angle is. This is because, hard target as Sapele is more likely to cause bullet deformation or fragmentation compared to soft target as Jelutong. This means that more contact time between the projectile and the target surface thereby reducing the interaction impulse which in turn, reduces the ricochet angle. Observations on Sapele sample also show that less damage was done compared to Jelutong sample, as can be seen in Figure 3.

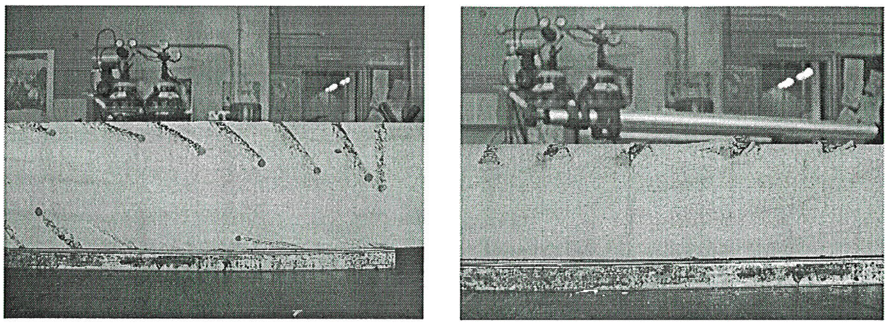

Figure 3. Cross-sectioned views of Jelutong (left) and Sapele (right) sample.

In Figure 4, Critical Ricochet angle where ricochet was first observed was plotted against the projectile velocity for all the three samples of target hardness. The figure shows that critical angle tend to increase as the target hardness increases. This is because, more energy is required for the projectile to penetrate Sapele rather than Jelutong target due to their respective hardness. The test showed that, with medium velocity projectile at ~150m/s impacting Jelutong samples, ricochet was first observed at 15° angle of incidence. Whilst, the same test on Sapele sample shows ricochet occurred at higher incidence angle of 40°. In term of penetrations, the result shows that Jelutong had the deepest penetration since it was the softest material and Sapele exhibits shallower penetration.

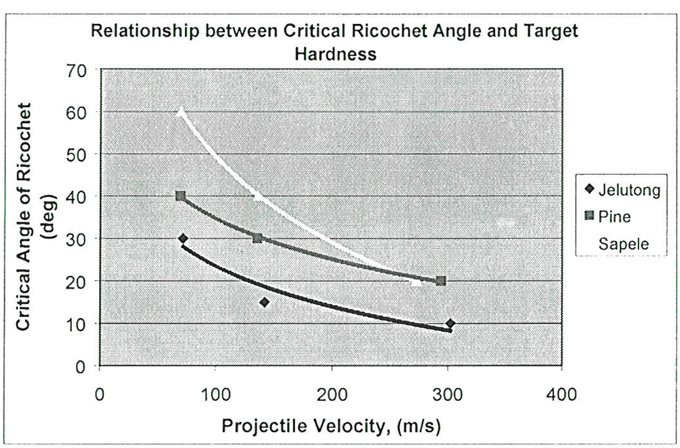

Figure 4. Relationship between Critical Ricochet Angle and Projectile Velocity on 3 types of wooden target.

CONCLUSION

Throughout this investigation, over 150 firing tests were conducted to study the effects of target hardness and angle of incidence on ricochet behavior after an impact on woods. The result showed that the angle of ricochet normally larger than the corresponding angle of incidence, regardless of the target material hardness. Ricochet angle was found to decrease with the increase of the target hardness, meanwhile the critical ricochet angle θ_c, increased with the increase of the target hardness.

ACKNOWLEDGEMENTS

The author would like to thank Dr. Robert S. Birch and Dr. R.A.W. Mines for the invaluable advice and guidance throughout this project. Last but not least, many thanks to Mr. Peter Smith and Mr. Steve Pennington from Impact Research Laboratory for their most kind assistance during the experimental stage of the study. Without their effort, this study would not have been completed.

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