The Damaged Analysis from Ballistic Threats on Transparent Armor

Chidchanok Chaichuenchob
Defence Technology Institute
Nonthaburi, Thailand
chidchanok.c@dti.or.th

Sujarinee Sinchai
Department of Materials Science, Faculty of Science,
Chulalongkorn University,
Phathumwan, Bangkok, 10330, Thailand
sujarinee.k@chula.ac.th

***Abstract*—Transparent armor is a group of transparent materials whose main role is providing the protection against high velocity projectile or fragment. It is known that the configuration of transparent armor have a big influence on the ballistic protection. In this study, various thicknesses of soda-lime glass sheets were laminated using PVB films as interlayers. The obtained transparent armor was ballistic tested by 7.62 mm FMJ ammunition at various projectile velocities. In all specimens, the ballistic penetration stopped at the first layer. The intercept counting method was used to determined the damage level appeared on the test specimen. It was found that the number of crack on the 12-mm-thick strike plate was higher than those in 19-mm-thick strike plate. However, the calculated new surface areas of these two specimens were in the same range which implied the similar amount of kinetic energy absorbed in the strike plates having different thickness. The cracks bifurcated were observed when the impact velocity was higher than 838 m/s.**

Keywords*— *transparent armor, cracks, ballistic impact

I. INTRODUCTION

General structure of transparent armor consists of multi-layer of glass laminated with thin polymer film. The bonding between these two materials should be strong and the reflective indices of both materials must be close in order to avoid distortion visibility. The bonding between polymer film and glass is processed under controlled pressure and temperature in an autoclave. This bonding holds the fragments those exhibited from ballistic treats; protecting the users from injury. Transparent armor is designed using various materials and configurations [1-5]. The purpose is to reduce weight, thickness and increase the ballistic protection performance of the specimen.

Therefore, the good design requires an understanding of the specimens' behavior under high velocity impact loads [6-8]. Shockey et al. [9] studied the failure of glass which impact tested by projectile rods at the velocities ranged from 300-600 m/s. They reported that the cracking patterns were corresponding with stress zone around the projectile. The target was loaded, damaged and displaced by sequent three steps of tensile, shear and compressive stress states.

It is known that glass has been widely used as a material for transparent armor because its low cost, high hardness and high compressive strength. However, glass has some mechanical properties, e.g., its brittleness, low toughness and low tensile strength, those limits the ballistic performance. Transparent armor is widely used in many applications, ranging from the general safety applications in laboratories to the highly protective applications in military combats. They are extensively installed in high security buildings and military ground vehicles, the side that is first attacked by the projectile impact is called "strike face". The strike face has a responsibility on stopping or decreasing the velocity of the projectile. When the projectile hits the transparent armor, the impact energy is transferred to the target materials. Within micro-second, the impact energy is converted to [10]: 1.Energy loss during impact; friction occurring when the projectile penetrates the armor body. As the strength of projectile is lower than armor, the projectile is shattered and eroded. 2.Material damage; the dissipation of impact energy that create a crater and various crack patterns. The crack patterns on transparent armor have been analyzed by Bless [11]. He reported that the cracks were propagated from the impact point to the edge of specimens. Chronological damage patterns, starting from the impact point; crater, bundled radial cracks, the outward fan cracks, the coarse radial cracks and the bow-tie cracks, were observed on the striking plate.

In this study, the crack evolution on transparent armor strike plate after ballistic tests using 7.62 mm FMJ ammunition were analyzed. Correlation between the resulted damages and the transparent armor configurations also were discussed.

II. MATERIALS AND METHODS

The transparent armor specimens were prepared with 305x305 mm^2 soda-lime glass and polyvinyl butyral (PVB) films (DuPont™ Butacite®). The glass thicknesses were varied from 3 to 19 mm and the film thickness was 0.76 mm. Lamination process consisted of rolling step at 65-80°C and vacuum step at 13.5 bar and 135°C. The laminated configurations designed for this study are shown in Fig.1. The total thickness of all specimens was 67.8 mm.

The ballistic tests were performed according to NIJ 0108.10 standard using 9.6 g Full Metal Jacketed (FMJ) 7.62 mm ammunition [12]. The amounts of gunpowder were adjusted in order to modify the projectile velocities (638±15, 738±15, 838±15 and 938±15 m/s). The projectile trajectory angle was

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