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Tribology at high-velocity impact☆

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Abstract

The tribological events taking place when a high-velocity projectile hits a SiC particulate reinforced AA 5083 composite material was examined under real conditions. The samples were cast in a disc shape by squeeze casting method. Different volume fractions of SiC particles were used. They were solidified under 180 MPa in a steel mould with a 650–700 °C temperature range. SiC particles with the size of 250–500 μm, and 30% and 45% in volume fraction were incorporated into the matrix material. The composites were machined to ensure a smooth surface and to obtain samples without burrs. The samples had a diameter and thickness of 140 and 20 mm, respectively. The terminal ballistic tests were carried out in an army zone under standard test conditions. An AP 7.62 mm armour piercing projectile with a speed of 710 m/s was used for testing the composite.

The frictional characteristics and wear mechanisms caused by high-velocity impacts to the composite were determined by SE microscopy studies. The evaluations of the tribological events on both the hole and projectile tip surfaces resulting from high-velocity friction were carried on. As the projectile moved thorough the composite, some material broke from the matrix body and conglomerated along the path followed by the missile. Then these conglomerated blocks yielded and slided along the hole surface. There were also scratching and local melting on the hole surface. Similarly, some ploughing took place on the hole, some SiC particles were removed from the matrix body by the friction effect of projectile and these particles were conglomareted on the tip surface of the projectile. Thus, the nature of wear mechanism on the projectile surface was predominantly abrasive while those of the friction surfaces of the composites were predominantly abrasion and melt wear.

Keywords: Metal matrix composites; Ballistic impact; Penetration; High-velocity impact

1. Introduction

Particle reinforced MMCs have the cumulative good properties of both ceramics and matrix materials. Although many studies have been carried out concerning the quasi-static properties of the composites, their tribological behaviour at higher velocities have not been investigated sufficiently. On the other hand, they are widely used in military, automobile, aerospace and defence industries due to their attractive properties. On military side, MMCs are used in jet fighters as structural and high-temperature engine components. The recognition of MMCs as maturing materials technology stimulated exploratory research related to the armour potential of this material [1]. Under dynamic loading conditions, such as penetration of projectile into MMCs armours, particulate-reinforced MMCs often sustain high strain rate deformations. The hypothesis that MMCs exhibit excellent work hardening under dynamic loading supports the observed ballistic performance [1–3].

Projectiles are in competition with armours. While the armour materials have been improved against primitive projectiles in recent years, the aimed effect of new projectiles are to pierce the armour. Therefore it is desirable that armour should be able to withstand the latest projectile type. This is a measure on the performance of the armour whether it is strong or not [4]. The mechanical properties gained with reinforcement of metals improve their piercing resisting properties. The penetration behaviour of the high-velocity projectiles is affected by the strength of MMC.

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Some researches on the properties of the hole surface generated by high-velocity projectiles have been pursued and novel experiment techniques have been established for the simulation of friction characteristics of high-velocity projectiles [5,6]. In addition, the ballistic tests were also carried out to evaluate the tribological properties of particle-reinforced MMCs [4–7]. The friction and wear characteristics of particle-reinforced MMCs were examined not only under laboratory conditions with relatively lower speed [8–11], but also through the pin-on-disc configuration under high speed [12,13]. Although many experimental works have been done to assess the wear and friction mechanisms at high-velocity [3,12–15], the experimental studies about projectile and MMCs friction under real conditions have not been many. Therefore, improving the metal matrix composites and understanding their strength against projectiles are new and important areas for investigation. The aim of this study is to evaluate the behaviour of projectile tip and hole surfaces caused by the ballistic impact of a high-velocity missile.

2. Materials and method

AA 5083 aluminium alloy has a wide range of application in armour material because of its favourable ballistic properties. For this reason this material was chosen as a test material. The chemical composition of AA 5083 is given in Table 1. The materials were cast at a temperature range of 650–700 °C by mixing with SiC particles at different volume fractions. They were solidified under 180 MPa in a steel mould by squeeze casting method. SiC particles with a size range of 250–500 μm and volume fraction of 30% and 45% were incorporated into the matrix material. The samples were machined with disc shaped in diameter of 140 mm and thickness 20 mm. The ballistic tests were carried out by a rifle (AK-47 gun, Kalashnikov) with a 7.62 AP (Armour Piercing) projectile having a speed of 710 m/s. The distance between the armour and the starting position of the projectiles was 15 m. The schematic illustration of the ballistic test setup with test parameters are given in Fig. 1.

Especially the friction and wear phenomena of the friction pair were investigated together with failure and deformation behaviours. Damage occurred at the tip surface of the projectile and hole surface caused by the high-velocity friction effect were examined by SE Microscopy.

Table 1
Chemical composition of matrix material

Materials	%Si	%Fe	%Cu	%Mn	%Mg	%Cr	%Zn	%Ti
5083	0.4–0.7	0.4	0.1	0.4–1	4.0–4.9	0.05–0.25	0.25	0.15

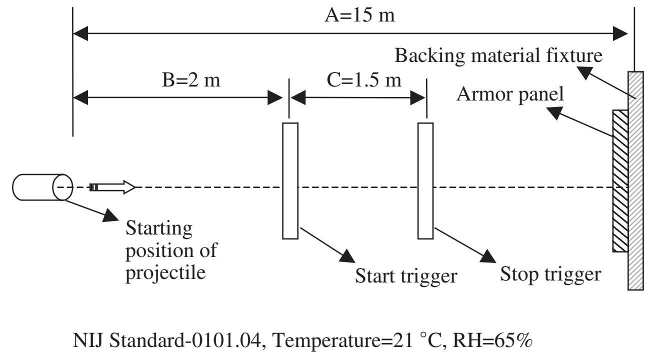

Fig. 1. Schematic illustration of the ballistic test setup.

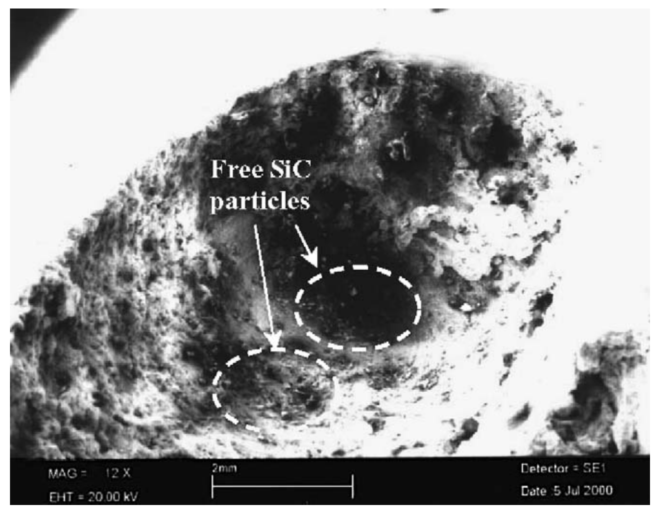

Fig. 2. Hole structure created by a projectile.

3. Results and discussion

It can easily be estimated that the friction characteristics between the high-velocity projectile and hole surface affect both the penetration depth and the direction of the projectile in MMC. When the compressing effect of projectile is considered, a strong correlation between the characteristic of MMC and hole structure can be observed. Fig. 2 shows the hole structure after a projectile is removed from hole. It can be seen that there are many SiC particles in the hole of the MMC. They were first shaken by the high-velocity projectile and then pulled off from the surface and became free particles. The freeing of particles is related to the strength of the bonding between particles and matrix material. The broken section of the entrance side of the hole can be seen in Fig. 3. There are some gaps produced by the particles removed from the matrix and a swelling near edge of the hole. Therefore, both the mechanical and bonding properties of the MMCs have an important role on their behaviour against high-velocity impact. Another view of entrance side of the hole in Fig. 4 shows that some blocked fractions of the matrix slided over each other or over the matrix due to the forcing effect of the projectile. The friction traces on the sliding areas can easily be seen.