# 6. Influence of Heat Treatment on the Ballistic Behavior of AA 7017 Alloy Plate against 7.62 Deformable Projectiles

## 6.1. Introduction

Most of the ballistic studies have been carried out against mainly 7.62 mm high hardness steel projectiles. A few studies have been attempted to understand the material behavior against 7.62 mm deformable lead projectiles. The 7.62 mm lead projectile deforms during the penetration process and has a different target defeat mechanism than that of the hard steel projectile. Therefore, it is essential to examine the material behavior against 7.62 mm deformable lead projectiles. This chapter is concerned with the investigation of ballistic properties of the 25 mm thick plates of AA 7017 alloy in different heat treated conditions by impacting against 7.62 mm deformable lead projectiles.

## 6.2. Results

### 6.2.1. Ballistic evaluation

The visual comparison of the front and rear side of the differently heat treated plates after ballistic evaluation is exhibited in Fig. 6.1. The material flows out to form perfect petalling damage pattern in the front side of the UA and OA plates. In contrast, a combination of broken petal and spalling damage is observed in the front face of the PA plates. Smooth bulging is seen in the rear face of all the heat treated plates. The bulge heights at the rear face are measured carefully and plotted for all the plates (Fig. 6.2). Interestingly,

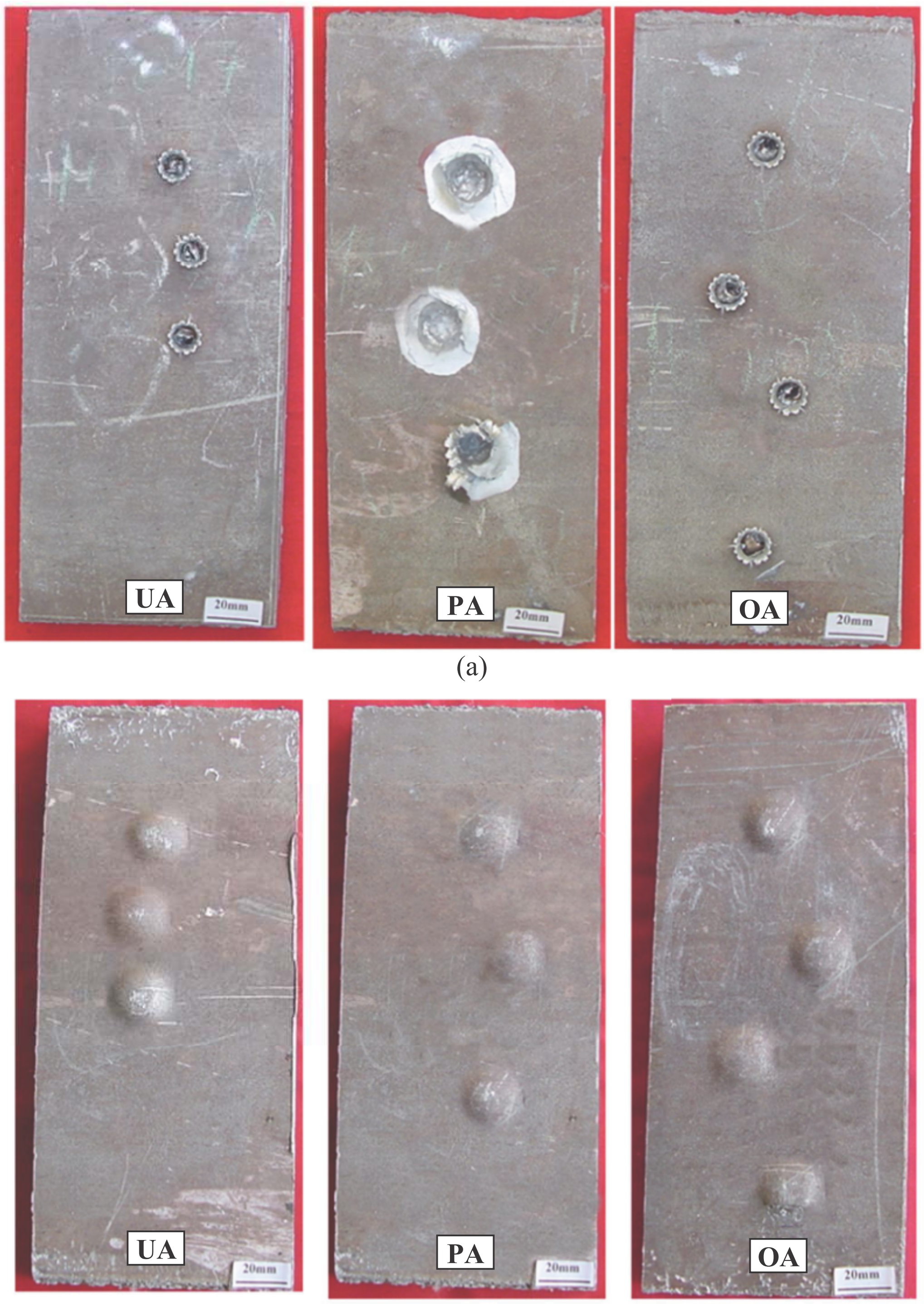


**Fig. 6.1: View of the target plate after ballistic impact: (a) Front face and (b) Rear face**

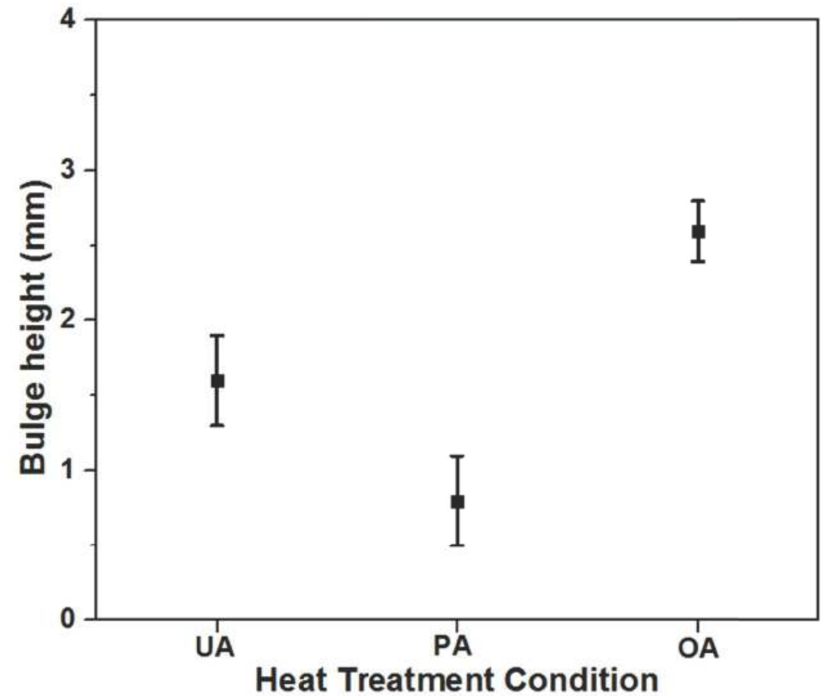


**Fig. 6.2: The bulge heights of UA, PA and OA plates.**

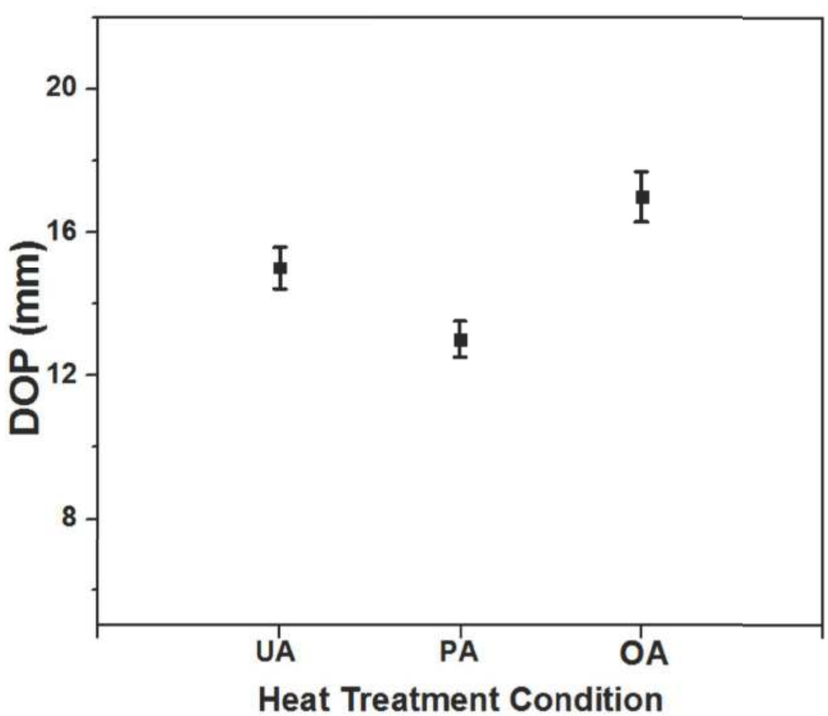


**Fig. 6.3: The variation of DOP values of UA, PA and OA plates.**

the bulge height is least in PA target in comparison to those of the UA and OA plates. The variation of ballistic performance of UA, PA and OA plates in terms of depth of penetration (DOP) is given in Fig. 6.3. It can be seen that the ballistic penetration resistance of the PA plates are superior to UA and OA plates.

The macroscopic comparison of the section views of the craters formed in different target plates after ballistic impact is shown in Fig. 6.4. The appearances of the penetration channel diameter observed in all target plates are higher than the original projectile diameter and the maximum in PA plate. Projectiles can be seen as wedged into the target after the ballistic testing in UA and OA plates.

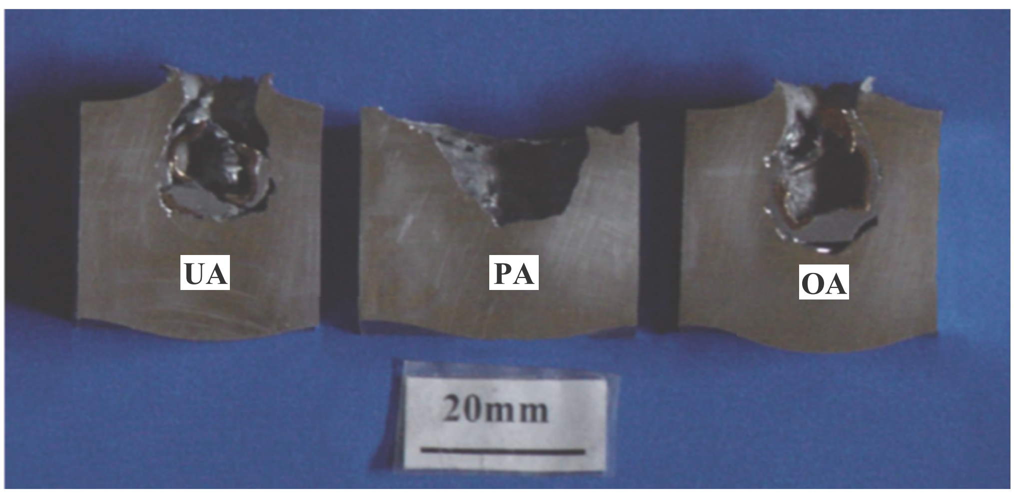


**Fig. 6.4: Half section view of the impacted craters of UA, PA and OA plates.**

### 6.2.2. Post ballistic microstructural characterisation

The impact craters are examined in detail to observe the changes in microstructure. The microstructure adjacent to the crater wall of the UA plate is shown in Fig.6.5. At the entry side, material flow lines are bent in opposite direction of projectile motion (Fig.6.5 (a and b)). This is followed by large deformation in remaining part of the crater region (Fig.6.5(c and d)). Small cracks are observed at the bottom of the crater (Fig. 6.5e). The microstructures also display the presence of extensive ASB. Cracks are seen to be initiated from ASB. The width of the crack widen as it moves towards the crater wall. An enlarged view of ASB

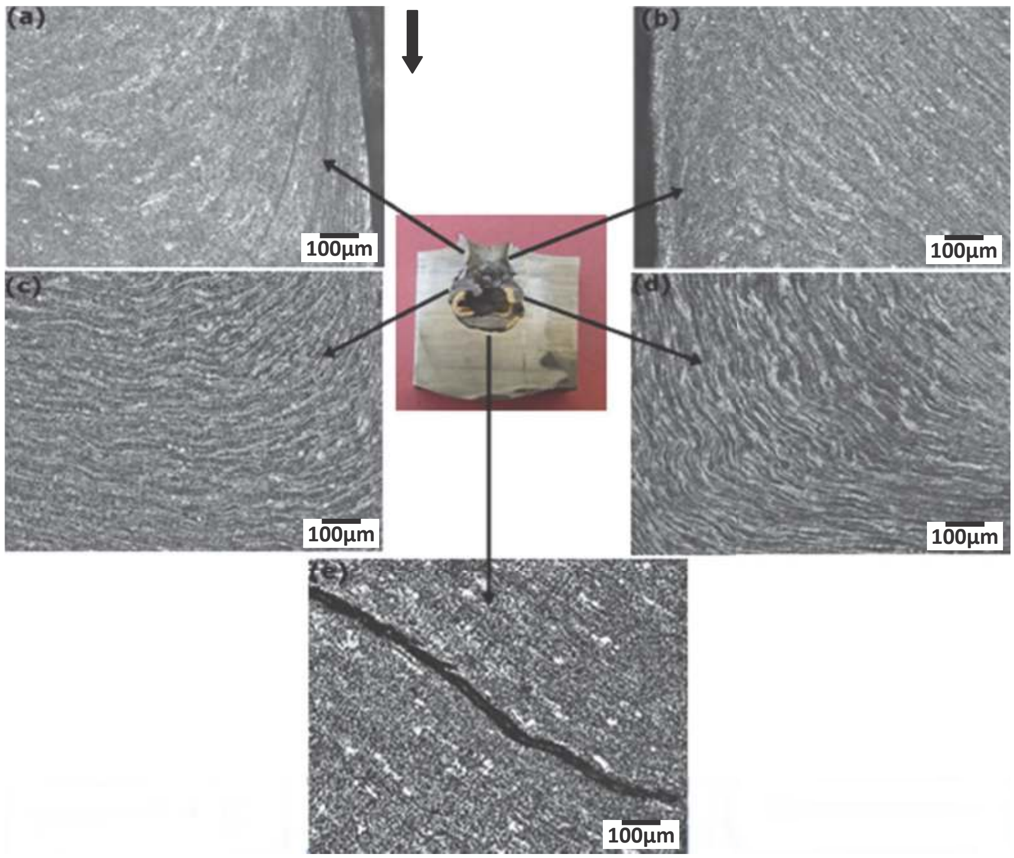


**Fig. 6.5: Optical microstructures of UA target plate adjacent to the crater wall. Arrow mark indicates the projectile penetration direction.**

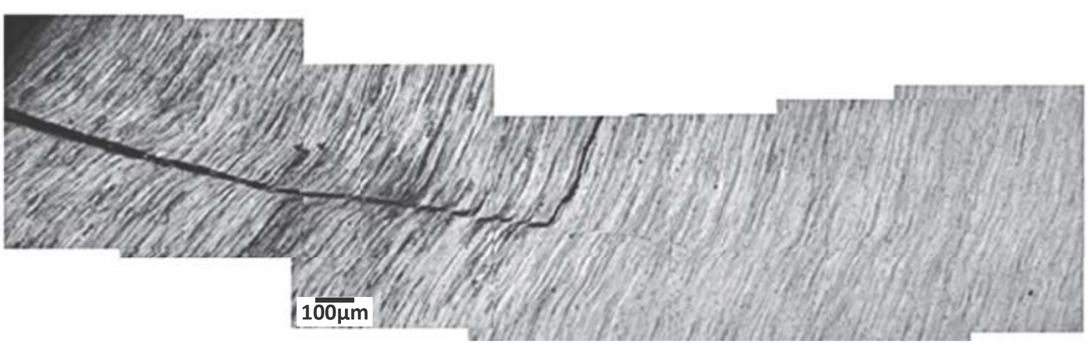


**Fig. 6.6: Adiabatic shear band (ASB) leading to crack initiation and propagation in UA target plate.**

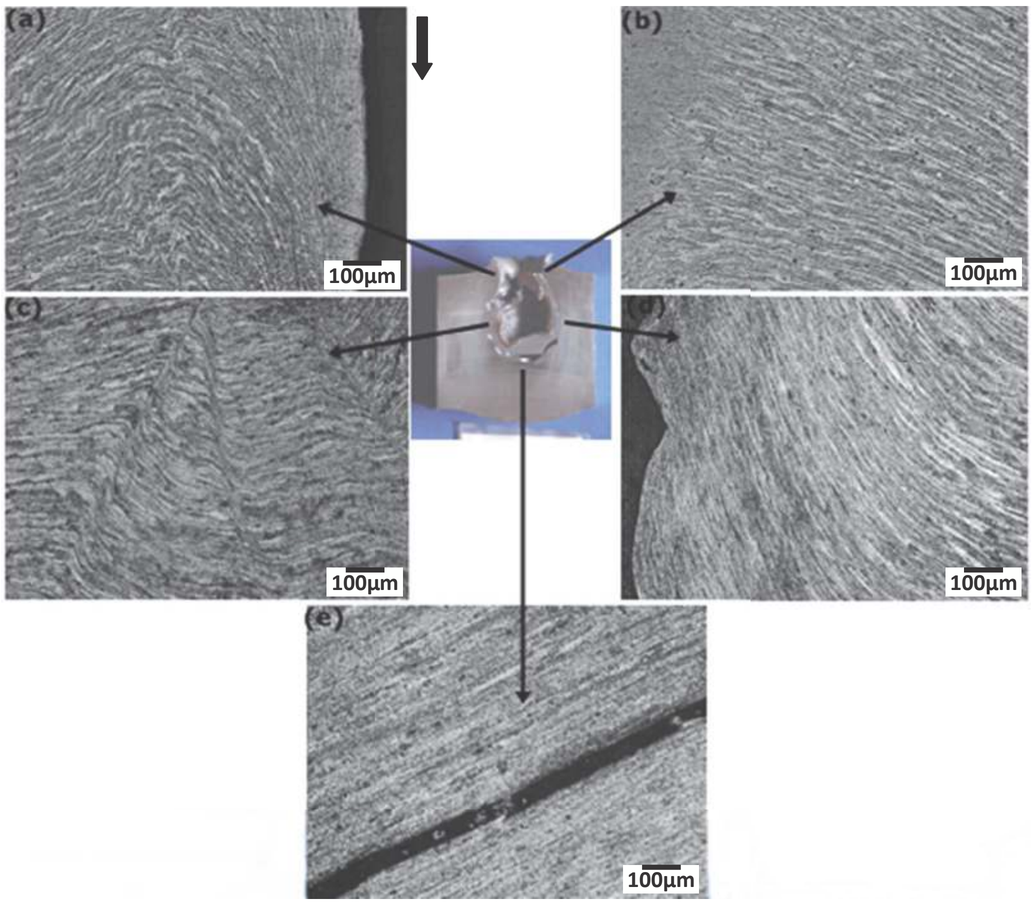


**Fig. 6.7: Optical microstructures of OA target plate adjacent to the crater wall. Arrow mark indicates the projectile penetration direction.**

leading to initiation, propagation and widening of a crack is shown in Fig.6.6.For the OA target plate, post ballistic microstructures are similar to those of the UA (Fig.6.7). However, more number of ASBs and ASBs leading to cracks are observed in OA target plate. The microstructures of the PA plate show lesser material deformation at the entry side of the projectile (Fig. 6.8). Only a few ASBs are observed in the impacted region.

### 6.2.3. Post ballistic micro-hardness measurements

Micro-hardness measurements are taken, starting from the bottom of crater and gradually moving away. Fig. 6.9 summarizes the variation in micro hardness values of UA, PA and OA target plates. All the target plates first show an increase in the hardness values followed by a gradual decrease. The PA target plate has displayed maximum extent of increase in hardness.

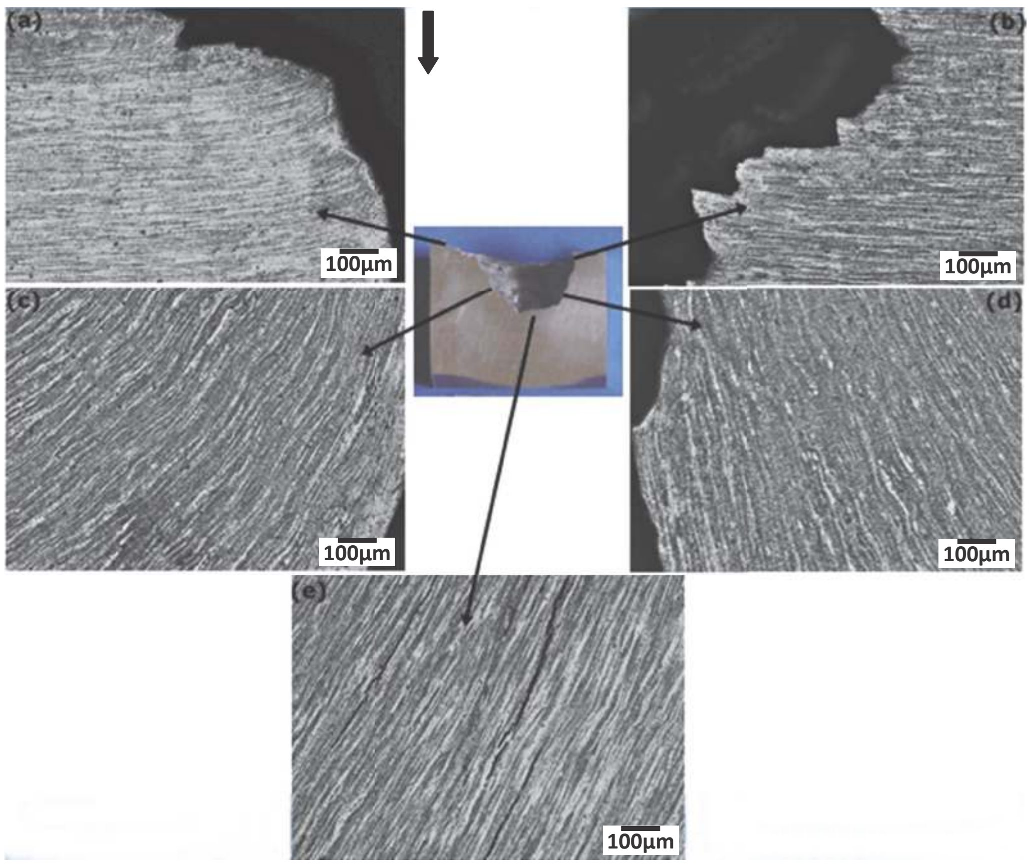


**Fig. 6.8: Optical microstructures of OA target plate adjacent to the crater wall. Arrow mark indicates the projectile penetration direction.**

## 6.3. Discussion

It is known that the kinetic energy is transferred to the target material during ballistic impact (Papukutty et al.,2003; Jena et al.,2010a). The target material absorbs the projectile's kinetic energy by plastic flow. Material properties like strength and hardness which resists the plastic flow, enhance the ballistic resistance. As a result, the PA target plate demonstrates superior ballistic resistance due to its higher strength and hardness. In a recent study by Borvik et al., it has been pointed out that the material strength is more critical than the ductility for the protection against small arms projectiles (Borvik et al., 2009). A number of other studies has also indicated similar correlation of strength and hardness with ballistic behaviour of materials (Dikshit et al.,1995; Übeyli et al.,2007).

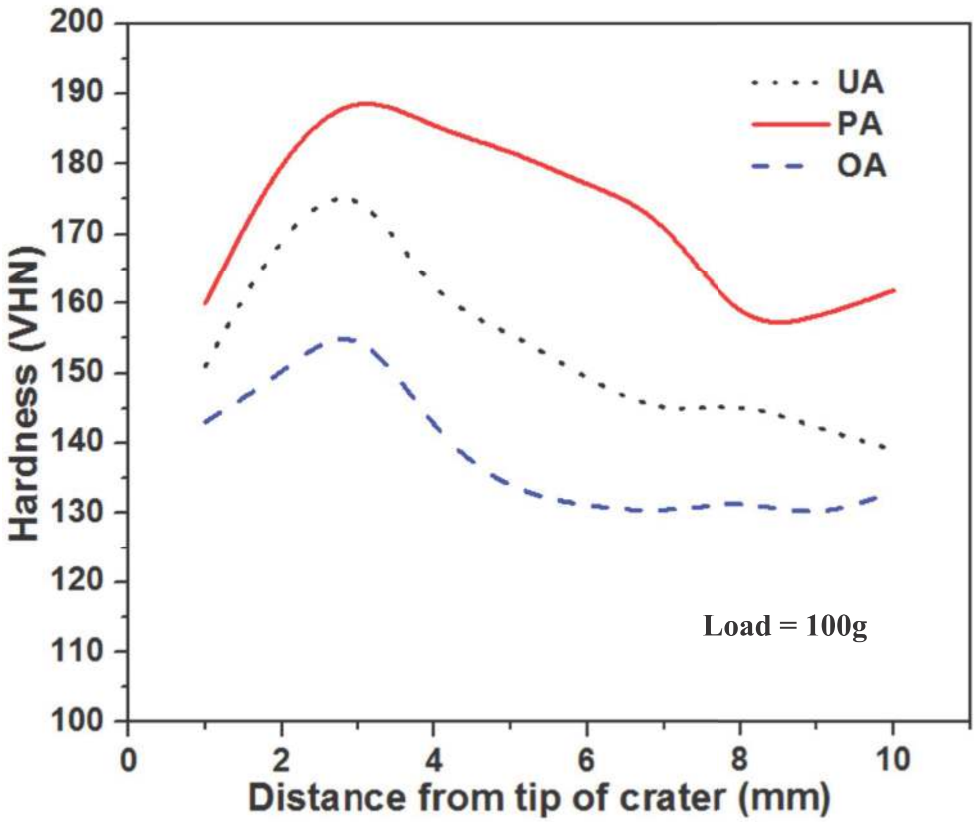


**Fig 6.9: Post ballistic micro-hardness measurements at the bottom of the crater of the target plates.**

For better ballistic performance, it is essential that the target material should be able to absorb as much energy of the projectile as possible in a homogeneous manner (Bhat,1985). It is well known that energy absorption in materials take place by plastic deformation, which can be delineated from post-ballistic microstructures. During ballistic impact, large amount of kinetic energy is distributed over a relative small volume of target material in a very short span of time. This leads to formation of ASBs which are the regions of instability (Jena et al., 2010b). These regions also provide easy path for propagation of cracks. In turn, it deteriorates the ballistic behavior of the material. Observation of lesser ASBs in the post-ballistic microstructure is in agreement with the superior ballistic behavior of the PA target plate.

The variation in hardness adjacent to the crater wall is a result of two competing processes. They refer to annealing effect introduced by rise in temperature after projectile impact as well as strain hardening caused by severe deformation. The hardness values adjacent to the crater wall give a good indication about the extent of material deformation. Higher the extent of deformation, more volume of the material is involved in absorbing the kinetic energy of the projectile. This in turn facilitates the material to absorb energy in a homogeneous manner. The micro-hardness results confirm to microstructural observations.

## 6.4. Conclusions

Ballistic penetration resistance of AA 7017 alloy plates against 7.62 deformable projectiles is in accordance with the strength and hardness values. ASBs are observed at the target projectile interface leading to cracks in all the plates. However, in PA target plates, the intensity of the adiabatic mode of failure is less and material deforms more homogeneously.