Flash X-Ray Radiography Technique to study the high velocity impact of soft Projectile on E-Glass/epoxy Composite Material

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Abstract

Flash x-radiography technique is extensively used in interior, intermediate, exterior and terminal ballistics and detonation research applications due to its penetrationability in events normally obscured by kinetic flash, luminescent gas clouds and explosive debris. In terminal ballistics, it is used to study the real time deformation patterns, of the projectile and target materials while the projectile is traversing through the target. However to acquire radiographic images of high quality, it is very essential to control various parameters such as x-ray source voltage, source to target and target to film distances as well as the angle between the various x-ray channels.
In the present paper optimization studies were carried out to avoid over exposure of the x-ray films. This has been carried out by using a metallic diaphragm and varying its distance between source and target. The study also involved, acquiring the real time deformation patterns of a 10 mm thick E-glass/epoxy composite laminates when subjected to impact of 9 mm soft lead projectile at different time intervals. It is observed that the deformation of the projectile increases with increase in the path length of the projectile in the target.

Keywords: *Flash x-ray, E-Glass/epoxy composite material, computed radiography, high velocity projectile impact*

1 INTRODUCTION

Flash x-ray radiography (FXR) has become an important diagnostic technique in the field of terminal ballistics and detonation research. In terminal ballistics, a projectile is launched in the velocity range of 300 m/s to 2000 m/s on to the different types of target materials. Real time imaging of the penetration events of the projectile in the target is very essential to analyze the ballistic efficiency of the target materials. During these events,bright light emission, light scattering, light absorption or reflection, debris formation etc occur in the surroundings. In such cases, most of the conventional optical diagnostic techniques like high speed photography, laser interferometry, schlieren photography etc are not efficient for imaging [1-2]. All these optical diagnostic techniques are also not useful for imaging the projectiles inside the target materials. FXR can be effectively used over the above optical techniques due to its advantages such as penetration ability through dust clouds and target materials. Penetration ability of x-rays depends on theenergy of x-ray beam.
Generally, Flash x-ray radiography system consists of x-ray tube, high voltage pulse generator and x-ray film scanner for converting the image on the film to digitized image.FXR system delivers the x-rays in the form of a pulse of a few micro seconds to nano seconds duration. The

penetration power of the x-rays depends on voltage between cathode and anode. For formation of image on the film high intensity of x rays are required. The intensity of x-rays depends on current flowing through the electrodes which is normally of the order of tens of kilo amperes [3-6]. To successfully capture the dynamic events, it is essential to understand various parameters such as x-ray penetration thickness defined as optimum distance traversed by the x-rays in the target material, clarity and size of the objects in the radiographic images.
In the present study, 450 kV flash x-ray system was used to study the optimization of x-ray penetration thickness or maximum absorption thickness of E-Glass/Epoxy material under static conditions. The effect of ratio of the target to film and source to target distances on the size and clarity of the lead objects was studied. Studies were also carried out to avoid the over exposure of the radiographic films using metallic diaphragm at different distances from the x-ray source. The deformation of the 9 mm soft lead projectile and E-glass/epoxy target material at different time intervals was also studied.

2 EXPERIMENTAL DESCRIPTION AND MATERIALS

2.1 Materials

E-glass fibre reinforced epoxy composite laminate was supplied from M/s.Peramali Wallace Pvt Ltd., Bhopal ,India. The mechnical properties of materialwere evaluated as per the ASTM standards and are shown in Table 1.

2.2 Static experiments

Experimental setup for static experiments is shown in the Figure 1a. The setup includes a450 kV Flash x-ray tube, target plate and film cassette containing imaging plate. The image plate is scanned through the CR NDT35 scanner to convert the image on the radiographic film into a digitized image. These experiments were carried out to optimize various parameters such as x-ray penetration thickness of the material and clarity of the images. The experiments were also carried to avoid the over exposure of the x-ray films. In these experiments lead symbols of different shapes were used to simulate the projectiles. The technical characteristics of the FXR system are tabulated at Table 2.The optimized parameters were used in dynamic experiments.

2.2.1 Optimization of x-ray penetration thickness

The experimental set up was arranged by clamping the E-glass epoxy composite specimen of various sizes ranging from 85 mm to 105 mm using C clamps as shown in Figure 1a. The distance between the x-ray source to E-glass/epoxy composite target and target to film was maintained 1500 mm and 250 mm respectively. The lead symbol "R" was fixed on the side of the sample, facing the x-ray tube. The captured radiographic images on each sample are shown in Figure 2.

2.2.2 Optimization of TF to ST ratio

The E-glass/epoxy composite of 30mm thickness was clamped and used as target in these studies. The distance between the x-ray sources to targetis kept constant at 1500mm. This distance was preferred based on the safety limits assessed for dynamic testing. The distance between the target and film cassette was varied from 150mm to 650mm. Diamond shaped lead symbol was placed on the side of the composite panel facing the x-ray tube. Radiographic images of the lead object on the composite were captured and shown in Figure 3.

Table 1. Mechanical properties of E-Glass/epoxy composite material

Resin Content (wt%)	Density (g/cc)	Tensile Strength (MPa)	Flexural Strength (MPa)	Inter Laminar Shear Strength(MPa)
20	2.01	350	340	35

Table 2. Main characteristics of the Flash x-ray source

Voltage (kV)	Current (kA)	Stored energy (J)	Dose at 1m (mR)	Pulse FWHM (ns)	Repetition rate	Anode	Cathode	Anode size (mm)
450	10	90	25	20-25	01 / Min.	Tungsten	SS-304	2.5

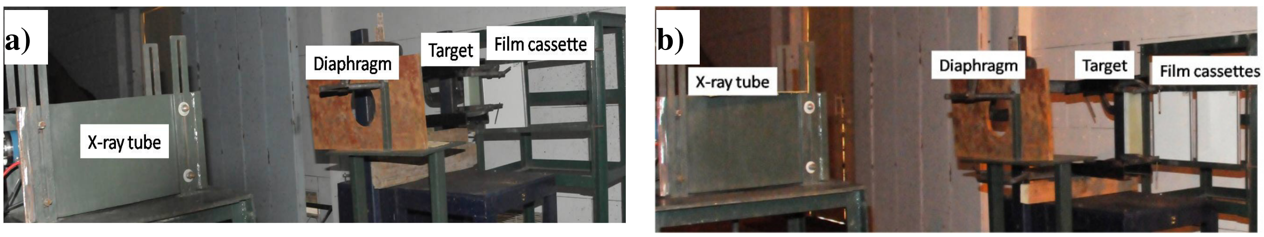


Figure 1. Experimental setup for a) static experiments b) For studies on overexposure

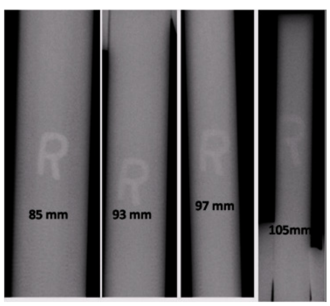


Figure 2. Radiographic images of different x-ray penetration thicknesses

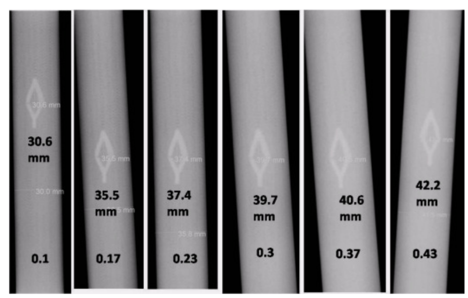


Figure 3. Radiographic images at various TF to ST ratios

2.2.3 Studies on over exposure

The experimental setup consists of x-ray tube and two x-ray film cassettes and shown in Figure1b. The distances between the source and target and target to film cassette were maintained at 1500mm and 250mm respectively.The radiographic image of the target was captured without diaphragm and is shown in Figure 4a. Other set of experiments was carried out with diaphragm.Mild steel plate of dimensions 600 mm x 300 mm x 20 mmwith 150 mm diameter circular hole was used as the diaphragm. The diaphragm was placed between the source and target to avoid over exposure. The distance between diaphragm and source was varied from 600 to 780mm and corresponding radiographic images were captured and shown in Figure 4b and 4c.

2.3 Dynamic experiments

The dynamic experiments on the E-glass/epoxy composites were carried out using 9mm soft lead projectiles at full velocity of 415 ±15 m/s. The schematic and photograph of experimental set up of the dynamic experiments areshown in Figure 5. The 9 mm soft projectiles were fired at

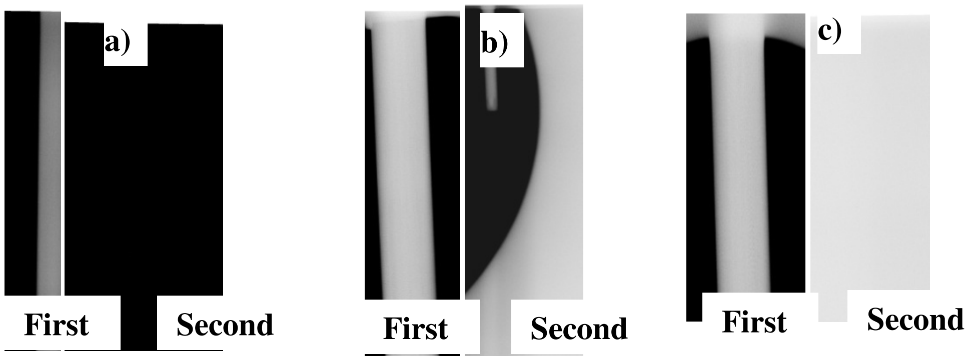


Figure 4. Radiographic images of target a) without diaphragm b) with diaphragmat 600 mm c) with diaphragmat 780 mm from x-ray source

an angle of 90° on to the E-glass/epoxy target which was clamped to target stand using C clamps.The Dimensions of the target are 150 mm x 85 mm x10 mm. Thex-ray tube was positioned in the thickness side of the target at 1500mm distance. The film cassette containing image plate was fixed at 250 mm distance on the other side of the target. The diaphragm was placed between the source and target at 780mm distance from the source to avoid overexposure. During the experiments Flash x-ray tube was triggered at different time intervals using the 500 µm aluminum foil which was fixed on to the target. The foil was connected to control panel of the x-ray tube through an electrical cable. When projectile hits the aluminum foil the cable short circuits and generates + 11 V electrical signal. This signal is fed into a delay generator. The delay generator produces a signal sufficient to trigger the 450kV Flash x-ray system to deliver the x-ray flash, after the programmedtime delay.The radiographic images of ballistic events were captured at 2.7, 5.8, 6.75, 10.8 and 20.8 µs after the impact of projectile on aluminum foil fixed to the target and the corresponding images are shown in Figure 6.

3 RESULTS AND DISCUSSION

3.1 Static experiments

3.1.1 Optimization of x-ray penetration thickness

The understanding of x-ray penetration thickness is very essential to capture the clarity images of the projectile in the target. From the figure it is observed that at 85mm x-ray penetration thickness, the x-ray image of the lead 'R' is very clear. But as the thickness increases from 85 mm to 97mm, the clarity reduced. And at 105mm thickness the lead 'R' is not visible in the image. The reduction in the clarity of the lead symbol in the images is due to the attenuation of x-rays with increase in thickness of specimen. Based on the maximum size requirements and the clarity of the images for ballistic events, specimens of 85mm x-ray penetration thickness were used for further studies.

3.1.2 Optimization of TF to ST ratio

In the ballistic events, to avoid damage to the x-ray tube and films it's very essential to keep them away from the target as much as possible. However, the distance between source to target and target to film affects the clarity and size of the objects in the image. From the Figure 3, at TF to ST ratio of 0.1 the size of lead diamond in the image is 30.6mm which is close to theactual size of the lead symbol. But as the TF to ST ratio increases from 0.1 to 0.43, the size of the lead symbol also increases in the same ratio which is due to the divergence of the x-ray beam. It is also observed from the figure that the clarity of the lead symbol reduces with increase in TF to ST Ratio which may be due to the attenuation of x-rays, before reaching the x-ray film. Keeping in view the film and x-ray tube distances from the target, size and clarity of the object in the images, TF to ST ratio of 0.17 is used in ballistic experiments.

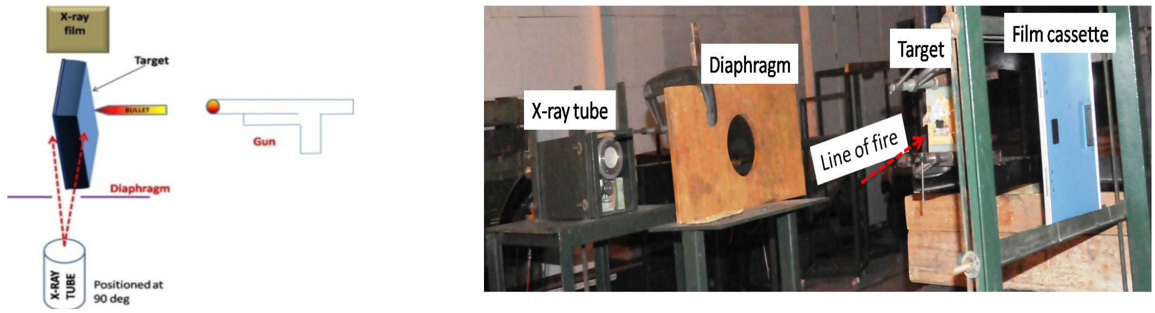
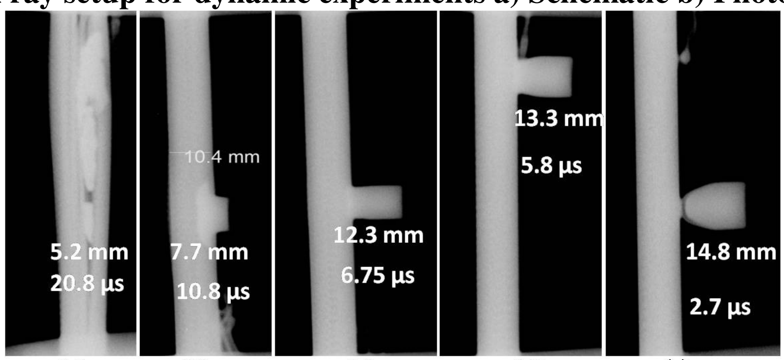


Figure 5. Flash x ray setup for dynamic experiments a) Schematic b) Photograph



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

Figure 6. Radiographic images of ballistic events at different time intervals

3.1.3 Studies on over exposure

Normally, x-ray image forms on the film when x-rays pass through the object and reach the film. Film turns black on direct exposure to the x-ray beam when there is no object. From the Figure 4, it is observed that when experiments were conducted without diaphragm, the image of the target was captured in the film cassette just behind the target. Though there was no image on the second film adjacent to the first one, it was turned black due to the exposure of the divergent x-ray beam. This over exposure creates problems while capturing the radiographicimages using multiple x ray sources. The overexposure was reduced when diaphragm was placed at 600mm from x-ray source but at 780mm the absence of black colour represents no overexposure of film.

3.2 Dynamic experiments:

The ballistic events of 9 mm soft lead projectile on E-glass/epoxy composite were capturedat different time intervals using 450 kV Flash x-ray system. From the Figure 6, it is observed that projectile just contacted the target at 2.7µs time delay after the impact on the aluminum foil and at this time,the size of the projectile was 14.8mm which is the actual size of the projectile. This indicates that projectile has not undergone any deformation. But the projectile size was 13.3, 12.3 and 7.7 mm at time delays of 5.8,6.75 and 10.8 µs respectively. The reduction in size of the projectile at different time delays is due to the more resistance offered by the target material as it traverses through the target. As it was lead projectile, it was flattened with impact on the target leading to its less penetration ability. Though the projectile got deformedup to 10.8 µs time delay, it has not fully penetrated the target material. The projectile was completely penetrated and arrested in the target at 20.8μs time delay. The size of the completely deformed projectile was observed to be 5.2 mm. From the Figure 6, no deformation of the target material was observed in the thickness direction up to 6.75μs time delay. This is due to the interaction of the projectile at the surface of the target only. At 10.8 μs time delay slight bulge was observed on the back side of the target material. This is due to the deformation of the projectile inside the target. At 20.8μs time delay delamination and bulging of the target material was observed and this leads to the arrest of the projectile.

4 CONCLUSIONS

A 450 kV Flash x-ray radiography system was used to capture the radiographic images of the E-glass/epoxy composites both under static and dynamic conditions. Following conclusionswere drawn from this study.

1. E- Glass / epoxy composites of 85 mm or lesser width samples are suitable for 450 kV Flash x-ray experiments. TF to ST ratio of 0.1 hasto be maintained to achieve good clarity of the images and actual size of the object in the image. However, 0.17 TF to ST ratio was used in this study to avoid damage to the x-ray tube and film cassette. The size of the object in the radiographic image increases proportional to TF to ST ratio.Over exposure of the x-ray film was avoided by using diaphragm of 150 mm diameter circular hole at 780 mm from the x-ray source.
2. The radiographic images of the ballistic event were captured at different time intervals. The projectile size decreases with increase in the time delay and completely arrested in between 10.8 and 20.8 μs time delays. The deformation of target material was started after 10.8 μs time delay and, delamination and bulging was observedat 20.8 μs time delay.

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