ABSTRACT

The present study aims to investigate the mechanical behaviour of different materials like AA2014-T6 and additively manufactured specimens of carbon and Kevlar-reinforced composite materials. Furthermore, these materials are also dynamically loaded under shock loading to investigate their behaviour under extreme loading conditions. AA2014-T6 is characterized under tension over a wide range of strain rates (10^{-4} to 10^{3} s^{-1}) by utilising a standard universal testing machine (UTM) and tensile split-Hopkinson pressure bar (TSHPB). It is found to exhibit the elastic-plastic flow behaviour associated with isotropic strain hardening. It is also found to exhibit positive strain rate sensitivity over the strain rates considered in the current study. For numerical modelling, the Johnson-Cook material model is found to effectively quantify the effect of strain hardening and strain rate hardening for the current aluminium alloy and predict its flow behaviour under the influence of extreme loadings such as shock and impact loadings. Similarly, the mechanical behaviour of additively manufactured specimens is also investigated under the influence of tension, compression and shear loading. The response of the Onyx specimens is found to be highly dependent on the print orientation of the specimens. Onyx specimens with a print orientation of $[\pm 45]_N$ are selected as matrix specimens to be reinforced with continuous carbon and Kevlar fibers to evaluate their effective properties under the influence of tensile and compressive loading. Similarly, Onyx specimens with a print orientation of $[0/90]_N$ are utilized for experimentally investigating the composite materials under the influence of shear loading. The above-selected print configurations are selected due to a combination of high failure strains, low

material strength and high stability in terms of low out-of-plane displacement (buckling) in compressive and shear loading.

For investigating the shock response of the materials, a double-stage shock tube (DSST) is designed and developed in-house, and six different possible configurations are experimentally investigated to quantify the effects of cross-sectional changes on the incident shock wave properties like velocity and peak pressure. Furthermore, a combined background-oriented schlieren (BOS) and digital image correlation (DIC) technique is incorporated for visualization and quantification of the spatial variation of the shock wave pressure in open air. A quadratic decay of the shock pressure and linear expansion of the shock wave is observed using the above technique. The obtained results are further utilized to approximate the actual loading conditions experienced by the simply supported specimens of AA2014-T6 material placed near the muzzle outlet of the DSST. A finite element analysis of the same is performed by utilizing ABAQUS/Explicit software where the specimen is categorized into three zones namely primary, secondary, and far-field zone. The size of the primary zone is considered equal to the muzzle outlet of DSST. The secondary zone is considered to encircle the primary zone with an area equal to the primary zone. The rest of the specimen geometry is considered to be a zone unaffected by the shock loading and thus termed a far-field zone. A modified shock loading based on the specimen geometry and combined BOS and DIC technique is also incorporated in FE investigations on the shock response of the specimens. Russel errors between the experimentally obtained and numerically computed deflections of specimens are evaluated and, are found to be within the limits ensuring an excellent agreement between both data. A parametric investigation on the shock response of the AA2014-T6 specimens is conducted to quantify the effects of specimen width, span length, overhang and thickness. Decreasing either of width or span length of the specimens is observed to increase the plastic deformation in the zone near the mid-span, whereas overhang change is observed to have a negligible effect on the shock response. Additionally, the 2 mm thick specimen is observed to be better shock resistant than a 1 mm thick specimen by converting a comparatively larger portion of input shock energy in the plastic deformation than the kinetic energy of the specimen. Furthermore, both 1 mm and 2 mm thick specimens are investigated for the effect of shock loading magnitude on the response of the specimens. Signs of extensive snap-back phenomena are observed at higher shock loadings in both sheet thicknesses in terms of reduced permanent deflection in the central zone with increased loading. The effect of sheet stacking on its shock response is also investigated for an effective thickness of 2 mm and 3 mm. The monolithic sheet of AA2014-T6 is found to be better shock-resistant than the stacked sheets of equivalent thickness. Furthermore, the multi-stacked configuration having thicker sheets facing the muzzle outlet is found to be performing better than the equivalent thickness configuration having thinner sheet facing the muzzle outlet of the shock tube.

The shock response of the additively manufactured specimens is also investigated experimentally. Two different print configurations of Onyx-only specimens with print orientations of $[\pm 45]_8$ and $[0/90]_8$ are investigated for their shock response at two shock loading magnitudes equivalent to incident shock wave velocity of ~600 m/s and ~750 m/s. A lesser deformation in the $[0/90]_8$ configuration specimen is observed than that in $[\pm 45]_8$ configuration specimen at both loading magnitudes. The Onyx $[0/90]_8$

configuration is further utilized to study the effect of both carbon and Kevlar reinforcement in different orientations and positions. For one-side reinforcement, specimens with longitudinal reinforcement at the rear side are observed to perform best in terms of out-of-plane displacement for both types of fiber reinforcement (carbon and Kevlar fibers). Among the various configurations having fibrous reinforcement on both sides of specimens, the carbon composite specimen with longitudinal reinforcement at both sides is observed to perform best till the front side fibers fail under compressive buckling. Only one carbon composite configuration among others considered in the current study, having longitudinal fibers at the rear side and transverse fibers at the front side of specimens, is observed to sustain the shock loading till the end of the analysis. On the other hand, the very same configuration of the Kevlar fiber reinforcement is observed to perform best among the other considered configurations both in terms of survivability and out-of-plane displacement. Sandwich specimens of AA2014-T6 and additively manufactured composite materials are also shock loaded to experimentally investigate the response of the sandwich specimens. AA2014-T6 metal sheet is utilized as a backing plate and is placed on the rear side of the sandwich. Two types of carbon and Kevlar fiber reinforcements are considered for investigation having either longitudinal or transverse fibers at both sides of the composite specimens, each facing the muzzle and aluminium backing sheet. Carbon composites are observed to outperform the Kevlar composites in the sandwich composite configurations. Furthermore, longitudinally reinforced composite specimens of both carbon and Kevlar fibers are observed to perform better than the transversely reinforced specimens.