AN APPARATUS FOR TENSILE CHARACTERIZATION OF THERMOPLASTICS AT INTERMEDIATE STRAIN RATES

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Thermoplastic polymers have seen rapid increase in automotive applications. Advances in nanofillers technology has seen these polymers compete with thermosets with respect to mechanical properties, light-weighting, emission control, precise manufacturing and high-volume processing. Unlike metals and thermosets, thermoplastics are relatively soft and their material response at intermediate strain rates (1 - 100s$^{-1}$), commonly experienced in automotive crashes, is not well-documented. The tendency of thermoplastics to undergo large deformations before yield and failure, places a limitation on the type of apparatus which can be used to characterize their tensile response at these strain rates. This complex polymeric material behavior has led to an apparent lack of experimental techniques required to generate reliable tensile stress–strain data and a resultant absence of robust constitutive equations based ‘digital twins’.
To address this challenge, a three-pronged approach was implemented. First, a novel, symmetric, double-acting drop weight impact apparatus that allows for pure-tensile testing at desired strain rates was designed and developed ‘in-house’ at the composite vehicle research center (CVRC). Equipped with an accurate data acquisition system, this fixture allows for application of equal displacement on both ends of the test sample, which results in efficient stress transfer throughout its gage length and a smoother transition to dynamic equilibrium. Two in-line load cells were used on both ends of the sample to record load data and ensure symmetric load application. Digital image correlation along with high-speed camera was used for obtaining strain information. The data acquisition system was automated with an optical trigger to ensure repeatability of response and facilitate data processing.

Second, the test fixture was validated with Aluminum 6061-T6 data reported in the literature corresponding to two unique strain rates. The experimentally validated fixture was then used for the third part of the work that focused on intermediate strain rate characterization of five commonly used automotive thermoplastics. The thermoplastics were divided into three classes based on their stiffness and ductility. Further, the effect of nanoparticle inclusions on resulting tensile response of one select polymer (Acrylonitrile Butadiene Styrene - ABS) was investigated. Three nanoparticles, two graphene platelets and one carbon nanotube, were used at 1% wt. The baseline for the rate dependent response of all thermoplastics was established by initially testing them at different strain rates within the quasi-static regime. Next, all thermoplastics were tested at three strain rates corresponding to fixed drop heights of 10 in., 20 in. and 25 in.

Results show a homogenous strain field in the gage length of all samples tested, indicating a stable impact velocity and load rising rate. Further, the load recorded on both
load cells was similar indicating symmetric loading. Importantly, little to no ringing was observed in the output load response eliminating the need for further signal processing.

In general, results indicate that with increasing strain rates, the tensile strengths increased whereas the failure strains (ductility) reduced. The material specific variations in strength and ductility for each polymer were different due to differences in microstructure and morphology. For example, at a strain rate of 27s$^{-1}$, the tensile strengths of ABS increased by 84% while failure strains reduced by 48%, compared to its quasi-static response. ABS nanocomposites exhibited improved strengths at higher strain rates relative to their quasi-static response. Nevertheless, it was lower than the pristine ABS response at similar strain-rate levels. This can be attributed to the improper dispersion of the nanoparticles as they were incorporated by mechanical mixing and no chemical compatibilization with host polymer was performed. Overall, the results showed that the new apparatus is reliable and repeatable for characterizing the tensile response of thermoplastic polymers at intermediate strain rates.

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