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Influence of the Projectile's Length on Interrupted Dynamic Tension Experiment Results

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Influence of the Projectile's Length on Interrupted Dynamic Tension Experiment Results

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Abstract- The main focus of this work is to discuss the influence of the projectile's length on the results of a Split Hopkinson Tension Bar (SHTB) experiment. By using the commercial software ABAQUS, finite element simulations of high-strain-rate tension experiments are accomplished on Aluminium 7017-T73 alloy specimens when varying the length of the projectile employed. The finite element analyses described herein are applied to simulate the effects of the variation of the projectile's length on the measurements obtained in the incident, reflected, and transmission bars. Different strain rates are obtained when varying the projectile's length always provided that its speed remains constant. The simulation results show that the projectile's length has a significant effect on the strain obtained in the specimen and also on the subsequent stress-strain curve of the specimen. In view of this research, it can be concluded that the projectile's length is a factor that can resolutely influence the interrupted dynamic tension experiment results since it has a significant effect on the strain obtained within the specimen. The simulations also provide complementary information to the experiments and an in-depth understanding of the specimen's behaviour.

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I. INTRODUCTION

Several techniques have been widely implemented in characterizing the high-strain-rate mechanical behaviour of engineering materials in order to optimize their use. The most common method for determining such dynamic behaviour is the Split Hopkinson Bar, which can be used both in tension (SHTB) and compression (SHCB). The Split Hopkinson Bar is used to test materials at strain rates as high as $10^4\ s^{-1}$. Simultaneously, damage evaluation and safety assessment of the integrity of structural elements under dynamic loading have recently drawn the attention of researchers. In this field, material dynamic response and dynamic constitutive material models are still necessary. The dynamic behaviour of materials studies have become increasingly relevant to many technological applications, such as those of Aeronautics, in which structural elements may undergo impacts due to the vulnerability of satellites and spacecrafts to collisions with space debris. It is also crucial in the Transportation Industry, in which under the hardest working conditions there is insufficient time for stress equilibrium to be achieved within the materials employed. Finally, it is also relevant in Ballistics, where modeling of armour panels under projectile impacts must become accurate.Quasi-static loading is applied so slowly that materials deform at a very low strain rate and therefore the inertia forces can be ignored. On the contrary, in a dynamic loading, impact involves a load which is quickly applied over a short time duration and therefore the inertia forces must be definitely considered. Whereas a quasi-static test can be interrupted at any time to study the microstructure of the material under a determined strain level, interrupting a dynamic test becomes an arduous issue.Therefore, the main focus of this work is to study the behaviour of materials under high strain rates and develop a tool which permits the materials being tested to undergo different levels of strain and strain rates in a controlled manner. In order to meet such requirements, the below-referred setup relevant to the viability of a SHTB model has been accomplished:

1. Finite element simulation of high-strain-rate tension experiments using different strain rates and projectile's lengths.
2. Comparison of the stresses and strains obtained at a determined strain rate and study of the influence of the projectile's length on the interrupted dynamic tension experiment results.
3. Design of a SHTB model when using an Aluminium 7017-T73 alloy in which the effect of the projectile's length can be taken into account.

II. EXPERIMENTAL APPARATUS

The SHTB apparatus as installed in the Universidad Carlos III de Madrid Engineering Laboratory shown in figure 1 involves two bars called the incident and the transmission bars, and a specimen sandwiched between them made of the material being tested. The cylindrical bars are manufactured in a sole piece to facilitate the wave propagation study. Their dimensions are suitable for optimizing the experiments.

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Figure 1: Split Hopkinson Tension Bar apparatus as installed in the Universidad Carlos III de Madrid Engineering Laboratory.

The yield strength of the material used to fabricate the bars must be high enough to withstand the strains reached during the experiment. Its remaining properties must be precisely determined in order to foster the most reliable results.

Two strain gauges mounted on the incident and transmission bars enable the stress waves to be measured, as shown in fig. 2. The information gathered by the strain gauges is sent to a data acquisition system that consists of a signal conditioner and an oscilloscope, where test data can be computed.

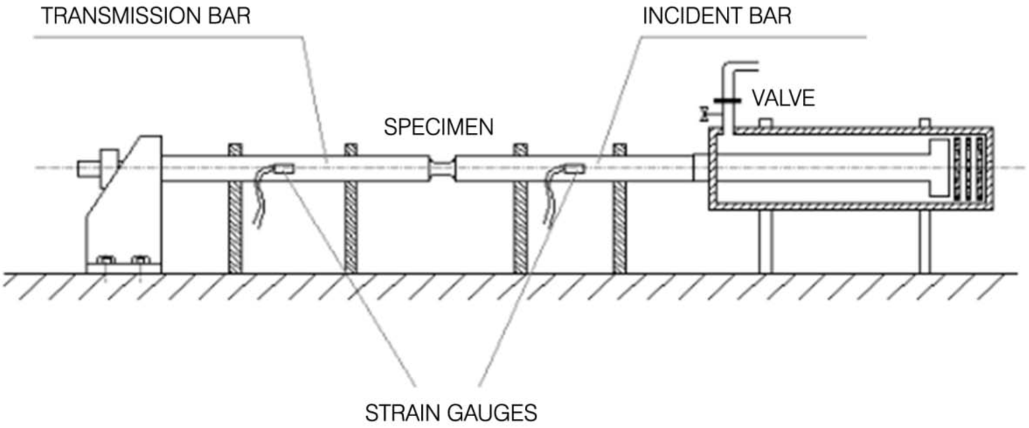

Figure 2 : Strain gauges mounted on the SHTB apparatus.

The specimen ends are screwed into both the incident and transmission bars. The incident bar, which is longer than the transmission bar, is impacted by the projectile.

The basic principle is to use a tubular projectile which impacts the flange of the incident bar to generate compression waves that will be converted to tensile waves by the flange. The projectile is a hollow cylinder that is launched using a chamber with compressed gas with a maximum pressure of 8 bar. The optimum pressure in every test for the required impact can be chosen using a control valve.

III. RESULTS

The primary assumptions of the SHTB analysis are the uniform deformation of the specimen and the absence of stresses in transverse direction. Other assumptions include a constant strain rate while testing and quick equilibration of stresses in the specimen. According to the one-dimensional wave theory and the assumption of a uniaxial and homogeneous stress and strain in the specimen, the stress, strain and strain rate can be therefore calculated. The one-dimensional elastic wave theory is valid only if wave dispersion due to three-dimensional effects (radial inertia of the bars) can be neglected. Therefore, the difference in the inner and outer elements considered must be negligible in the FE model as well.

All data shown below are relevant to the centre of the specimen (i.e. the area in which stresses and strains in the specimen reach their maximum values). Four elements are selected both in the incident and transmission bars at the strain gauge's height. They areplaced at a distance equal to 0, 4, 7.5, and 11 mm with respect to the centre of the bar.

The graphs depicted in figures 3 and 4 illustrate that there is no significant difference in the values obtained from the four elements considered.

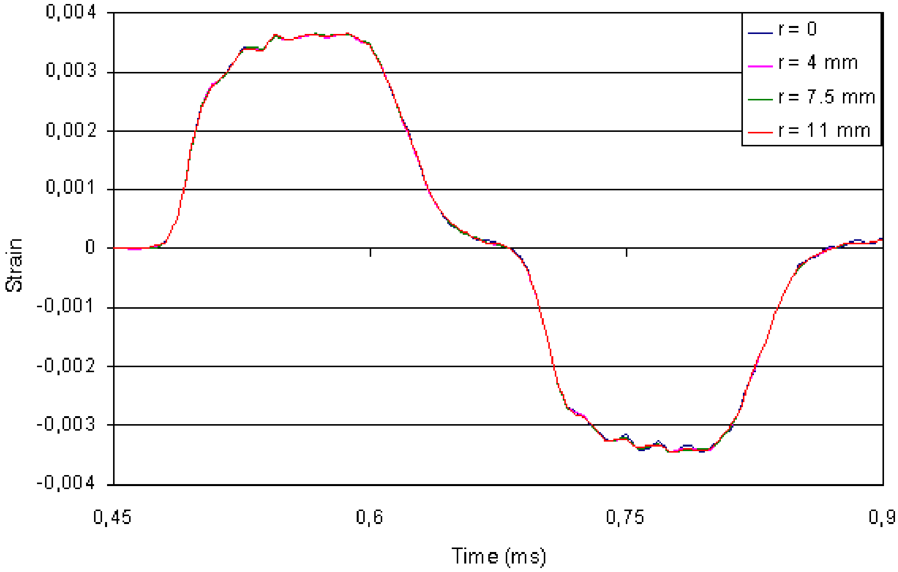

Figure 3 : Variation of strain with time as reached in four different elements of the incident bar placed at a distance equal to 0, 4, 7.5, and 11 mm.

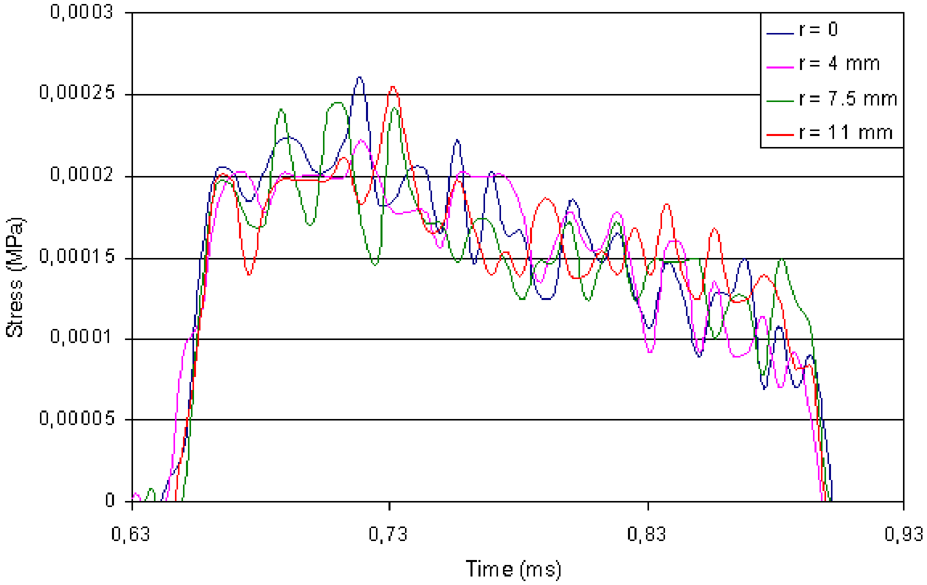

Figure 4 : Variation of strain with time as reached in four different elements of the transmission bar placed at a distance equal to 0, 4, 7.5, and 11 mm.

The one-dimensional wave theory is met for a strain rate equal to 1,300s^{-1}and a 33-cm long projectile. Other numerical simulations are accomplished to obtain the stress, the strain, and the strain rate corresponding to 20-cm long, 40-cm long, and 55-cm long projectiles.

Figure 5 shows the influence of the projectile's length on the behaviour of the incident and reflected waves.

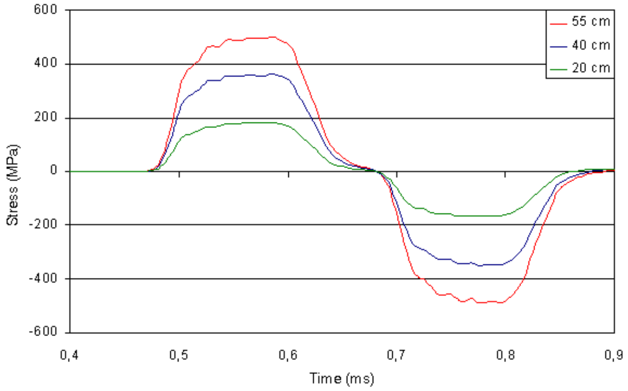

Figure 5 : Incident and reflected stress waves caused by the 20-cm long, 40-cm long, and 55-cm long projectiles.

The longest projectile produces a wave in which the stress values become the highest ones. On the contrary, the shortest projectile produces a wave in which the stress values happen to be the lowest ones. The incident wave caused by the 55-cm long projectile yields a maximum stress value equal to 480 MPa and the reflected wave relating to such projectile's length turns out a maximum stress value equal to 455 MPa. The incident wave caused by the 40-cm long projectile reaches a stress value of 350 MPa and the pertaining reflected wave yields 330 MPa. 175 MPa are reached by the incident wave and 155 MPa by the reflected wave when using the 20-cm long projectile. As shown in fig. 5, the incident wave is larger than the reflected one. This is due to the strike of the incident wave, which is partly reflected and partly transmitted to the specimen.

Every wave starts at 0.47 msand there is a slight difference in time duration when comparing the time values obtained by each projectile. The highest duration corresponds to the longest projectile. Such difference is minimal, since the waves' speed is really high(close to 5,170 m/s).

Another significant difference can be noticed when switching over from the incident wave to the reflected one. In this case the wave relevant to the shortest projectile tends to become horizontal, whereas those of the other ones remain inclined along the same portion of the curve. It can also be observed that the wave pertaining to the longest projectile happens to be the most inclined one. This occurrence shows that the longer the projectile is, the longer the time duration of the wave.

The transmitted waves are taken from the transmission bar of the model. The measurements are also taken from the points in which the strain gauges are placed in a real experiment. Figure 6 illustrates the influence of the rojectile's length on the behaviour of the transmitted waves.

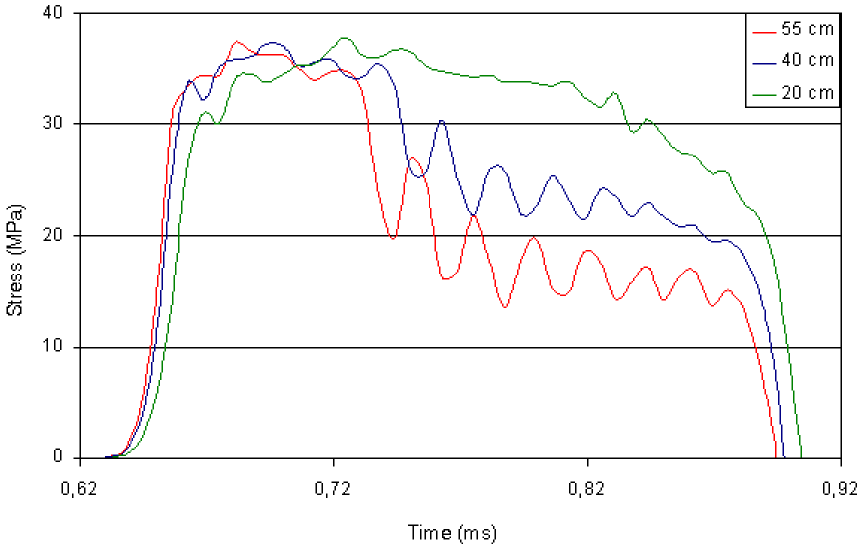

Figure 6 : Transmitted stress waves caused by the 20-cm long, 40-cm long, and 55-cm long projectiles.

Figure 6 shows that the maximum values of the waves transmitted by both the 55-cm long and the 40-cm long projectiles are alike. This occurrence is due to the high strains reached by the specimen, which are actually over its failure strain. Therefore, under such conditions the specimens would break after necking.

On the contrary, the specimen undergoes lower strain values when it isimpacted by the 20-cm projectile. The specimen does not reach its ultimate tensile strength and therefore no necking effects are observed in the specimen. Figure 7 shows the strain values caused in the midpoint of the specimen's gauge length resulting from the impacts of projectiles with different sizes. It can be observed that the highest strains turn out to occur when using the longest projectiles. The slope of the linear portions of each curveindicates the value of the strain rate. Since the steepest slope is that of the 55-cm long projectile, it can be inferred that the longest projectile causes a higher strain rate than the others.

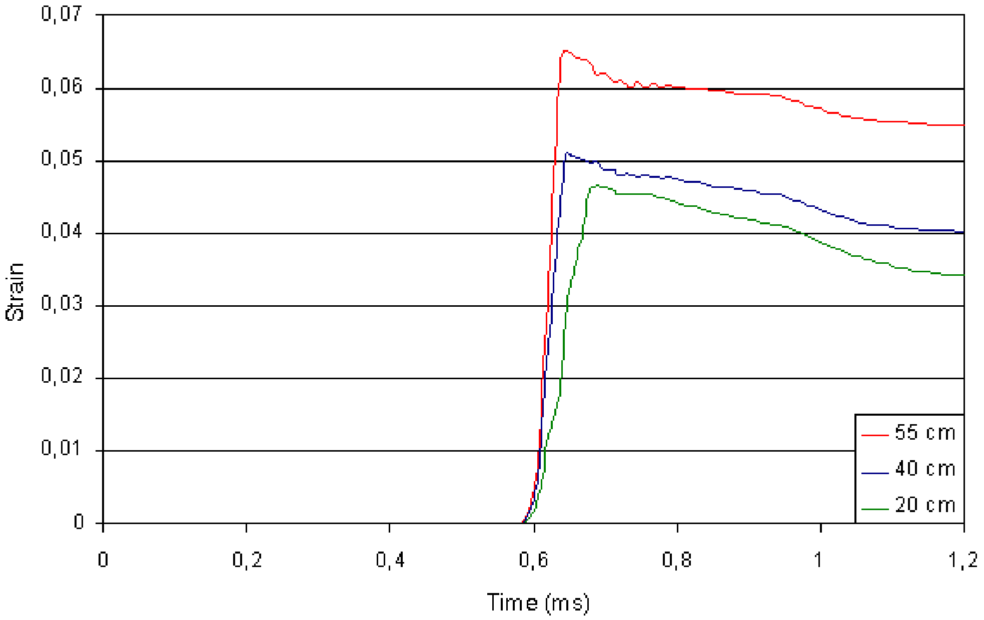

Figure 7: Variations of strain with time in the specimen caused by the 20-cm long, 40-cm long, and 55-cm long projectiles.

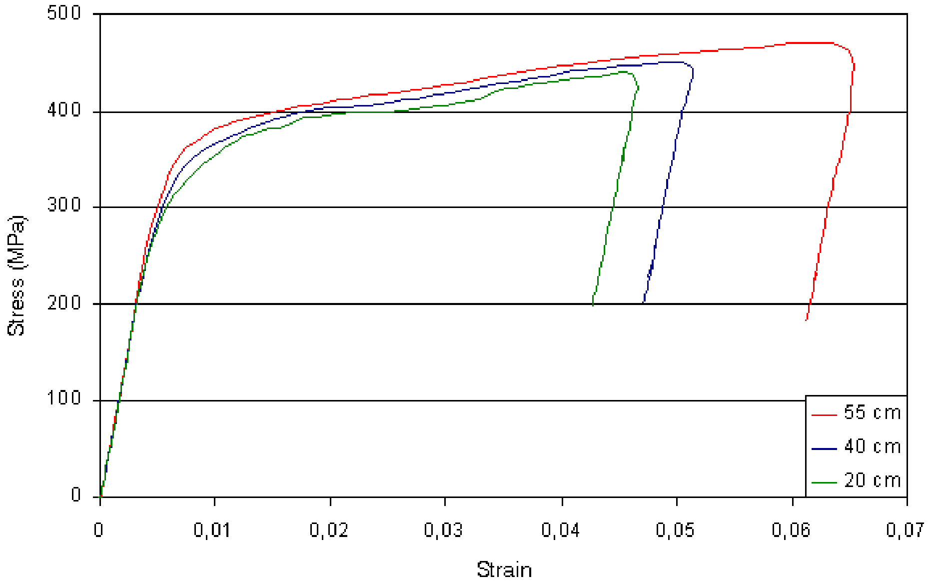

Figure 8 : Stress-strain curves in the specimencaused by the 20-cm long, 40-cm long, and 55-cm long projectiles.

The strain rate of the specimen is computed as the derivative of the variation of strain with time at the midpoint of the sample. Figure 9 shows the values of strain rates obtained when using different lengths of the same projectile.

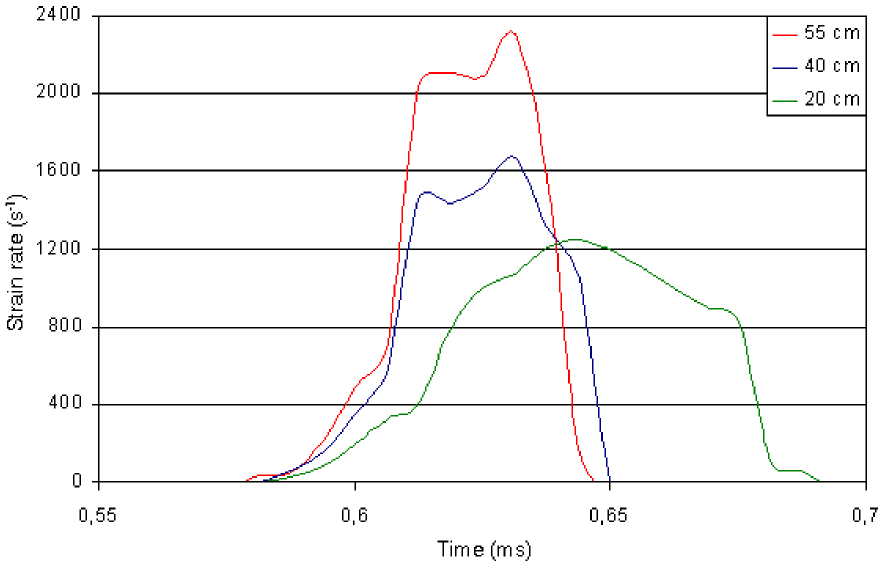

Figure 9 : Strain rates obtained when using the 20-cm long, 40-cm long, and 55-cm long projectiles.

It can be observed that the 55-cm long projectile impacts at a strain rate equal to 2100s^{-1} approximately, whereas the 40-cm long projectile reaches a maximum value of the strain rate which is in the region of 1500s^{-1}.The 20-cm long projectile impacts around 1000s^{-1}.

IV. Conclusions

A numerical analysis of the SHTB experiments was accomplished by using the FE method. Results of numerical simulations of SHTB experiments were presented considering different projectile's lengths. Different strain rates wereobtained when varying the projectile's length always provided that its speed remained constant. The simulation results show that the projectile's length has a significant effect on thestrain obtained in the specimen. The 20-cm long projectile yields the highest time duration. It was observed that necking takes place in the portion of the gauge length which is closer to the incident bar. The maximum stress values concentrate in such portion and therefore it undergoes the maximum strain values. The higher the strain rate is, the lower its time duration. The strains and strain rates obtained are higher when using the 50-cm long projectile.It can be deduced that if specimens with higher ultimate tensile strength are to be tested, the impact pressure in the incident bar must increase or otherwise longer projectiles must be used.

V. ACKNOWLEDGEMENTS

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REFERENCES RÉFÉRENCES REFERENCIAS

1. González-Lezcano, R.; del Río, J.M. Numerical analysis of the influence of the damping rings' dimensions on interrupted dynamic tension experiment results. J Strain Analysis 2015
2. Harding J and Welsh L. A tensile testing technique for fiber-reinforced composites at impact rates of strain. J Mater Sci 1983; 18(6): 1810–1826.
3. Lindholm U and Yeakley L. High strain-rate testing – tension and compression. ExpMech 1968; 8(1): 1–9.
4. Albertini C and Montagnani M. Wave-propagation effects in dynamic loading. NuclEng Des 1976; 37(1): 115–124.
5. Nicholas T. Tensile testing of materials at high-rates of strain.ExpMech 1981; 21(5): 177–185.
6. Staab G and Gilat A. A direct-tension split Hopkinson bar for high strain-rate testing. ExpMech 1991; 31: 232–235.
7. Thakur A, Nemat-Nasser S and Vecchio K. Dynamic Bauschinger effect. Acta Mater 1996; 44(7): 2797–2807.
8. Verleysen P and Degrieck J. Experimental investigation of the deformation of Hopkinson bar specimens. Int J Impact Eng 2004; 30(3): 239–253.
9. Gray GT. Classic split-Hopkinson pressure bar testing. Materials Park, OH: ASM International, 2000, pp.462–476.
10. Gama BA, Lopatnikov SL and Gillespie JW. Hopkinson bar experimental technique: a critical review. ApplMech Rev 2004; 57(4): 223–250.
11. Gerlach R, Kettenbeil C and Petrinic N. A new split Hopkinson tensile bar design. Int J Impact Eng 2012; 50: 63–67.
12. Kolsky H. An investigation of the mechanical properties of materials at very high rates of loading.ProcPhysSoc B 1949; 62(11): 676.
13. Rio T, Barbero E, Zaera R, et al. Dynamic tensile behaviour at low temperature of CFRP using a split Hopkinson pressure bar. ComposSciTechnol 2005; 65(1): 61–71.
14. Van Slycken J. Advanced use of a split Hopkinson bar setup application to TRIP steels. Doctoral Thesis, Ghent University, Belgium, 2008.
15. Hamouda A and Hashmi M. Testing of composite materials at high rates of strain: advances and challenges. J Mater Process Technol 1998; 77(1–3): 327–336.
16. Khlif M, Masmoudi N and Bradai C. Polypropylene tensile test under quasi-static and dynamic loading. In: Materials science and technology conference and exhibition (MS&T), 2012.
17. Verleysen P, Benedict V, Verstraete T, et al. Numerical study of the influence of the specimen geometry on Split Hopkinson bar tensile test results. Lat Am J Solids Struct 2009; 6(3): 285–298.
18. Kaiser MA. Advancements in the split Hopkinson bar test. Master's Thesis, Virginia Polytechnic Institute and State University, Blacksburg, VA, 1998.
19. Swantek S, Wicks AL and Wilson L. An optical methodof strain measurement in the split Hopkinson pressurebar. In: Wicks AL (ed.) Proceedings of IMAC-XIX: a conferenceon structural dynamics (vol. 2; Volume 4359 ofProceedings of SPIE). Bethel, CT: Society for ExperimentalMechanics, 2001, pp.1471–1477.
20. Pe´rez-Martı´n MJ, Erice B and Galvez F. On the loadingratedependence of the Al 7017-T73 fracture-initiationtoughness.Procedia Mater Sci 2014; 3: 1026–1031.
21. RodriguezPerez J. Analisis y desarrollo de metodologías para la obtención de propiedades mecanicas de materialesa altas velocidades de deformación y a alta temperatura,Universidad Complutense de Madrid, 2002.
22. Resnyansky A. Study of influence of loading method onresults of the split Hopkinson bar test. Structural Failureand Plasticity (IMPLAST), 2000, pp. 597–602.
23. Yang X, Xiong X, Yin Z, et al. Interrupted test ofadvanced high strength steel with tensile split HopkinsonBar method. ExpMech 2014; 54(4): 641–652.
24. Nemat-Nasser S, Isaacs J and Starrett J. Hopkinson techniques for dynamic recovery experiments. Proc R SocLond A: Math Phys EngSci 1991; 435: 371–391.
25. Dongfang M, Danian C, Shanxing W, et al. An interruptedtensile testing at high strain rates for pure copperbars. J Appl Phys 2010; 108(11): 114902.
26. Essa YES, Lopez-Puente J and Perez-Castellanos JL.Numerical simulation and experimental study of amechanism for Hopkinson bar test interruption. J StrainAnal Eng Des 2007; 42(3): 163–172.
27. Lezcano R, Essa YES and Perez-Castellanos J. Numericalanalysis of interruption process of dynamic tensiletests using a Hopkinson bar. J Phys IV 2003; 110: 565–570.

28. ASTM E8/E8M-13a: standard test methods for tensiontesting of metallic materials. West Conshohocken, PA:ASTM International, 2013, http://www.astm.org
29. Wu X and Gorham D. Stress equilibrium in the splitHopkinson pressure bar test. J Phys IV 1997; 7(C3): 91–96.
30. Jiang F and Vecchio KS. Hopkinson Bar loaded fractureexperimental technique: a critical review of dynamic fracturetoughness tests. ApplMech Rev 2009; 62(6): 060802.
31. ABAQUS (version 5.8). Pawtucket, RI: Hibbitt, Karlsson& Sorensen, Inc., 1999
32. Godunov SK and Romenskii EI. Elements of continuummechanics and conservation laws. Novosibirsk: SpringerScience+Business Media, 2003.