

# Influence of the Projectile's Length on Interrupted Dynamic Tension Experiment Results By RA González-Lezcano & JM del Río

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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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**Index terms**— tension experiment, high-strain-rate testing, stress-strain curve, finite element method, split hopkinson tension bar, mechanical characterization.

## 1 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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42 hopkinson tension bar, mechanical characterization.

## 43 2 I. Introduction

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

## 65 3 Comparison of the stresses and strains obtained at

66 a determined strain rate and study of the influence of the projectile's length on the interrupted dynamic tension  
67 experiment results. 3. Design of a SHTB model when using an Aluminium 7017-T73 alloy in which the effect of  
68 the projectile's length can be taken into account.

## 69 4 II. Experimental Apparatus

70 The SHTB apparatus as installed in the Universidad Carlos III de Madrid Engineering Laboratory shown in  
71 figure 1 The yield strength of the material used to fabricate the bars must be high enough to withstand the  
72 strains reached during the experiment. Its remaining properties must be precisely determined in order to foster  
73 the most reliable results.

74 Two strain gauges mounted on the incident and transmission bars enable the stress waves to be measured, as  
75 shown in fig. 2. The information gathered by the strain gauges is sent to a data acquisition system that consists  
76 of a signal conditioner and an oscilloscope, where test data can be computed. The specimen ends are screwed  
77 into both the incident and transmission bars. The incident bar, which is longer than the transmission bar, is  
78 impacted by the projectile.

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

## 83 5 III. Results

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

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

95 The graphs depicted in figures 3 and 4 illustrate that there is no significant difference in the values obtained  
96 from the four elements considered. The one-dimensional wave theory is met for a strain rate equal to  $1,300 \text{ s}^{-1}$   
97 and a 33-cm long projectile. Other numerical simulations are accomplished to obtain the stress, the strain,  
98 and the strain rate corresponding to 20-cm long, 40-cm long, and 55-cm long projectiles. The longest projectile

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99 produces a wave in which the stress values become the highest ones. On the contrary, the shortest projectile  
100 produces a wave in which the stress values happen to be the lowest ones. The incident wave caused by the  
101 55-cm long projectile yields a maximum stress value equal to 480 MPa and the reflected wave relating to such  
102 projectile's length turns out a maximum stress value equal to 455 MPa. The incident wave caused by the 40-cm  
103 long projectile reaches a stress value of 350 MPa and the pertaining reflected wave yields 330 MPa. 175 MPa  
104 are reached by the incident wave and 155 MPa by the reflected wave when using the 20-cm long projectile. As  
105 shown in fig. 5, the incident wave is larger than the reflected one. This is due to the strike of the incident wave,  
106 which is partly reflected and partly transmitted to the specimen.

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

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

115 The transmitted waves are taken from the transmission bar of the model. The measurements are also taken  
116 from the points in which the strain gauges are placed in a real experiment. Figure 6 Figure 6 shows that the  
117 maximum values of the waves transmitted by both the 55-cm long and the 40cm long projectiles are alike. This  
118 occurrence is due to the high strains reached by the specimen, which are actually over its failure strain. Therefore,  
119 under such conditions the specimens would break after necking.

120 On the contrary, the specimen undergoes lower strain values when it is impacted by the 20-cm projectile.  
121 The specimen does not reach its ultimate tensile strength and therefore no necking effects are observed in the  
122 specimen. Figure 7 shows the strain values caused in the midpoint of the specimen's gauge length resulting from  
123 the impacts of projectiles with different sizes. It can be observed that the highest strains turn out to occur when  
124 using the longest projectiles. The slope of the linear portions of each curve indicates the value of the strain rate.  
125 Since the steepest slope is that of the 55-cm long projectile, it can be inferred that the longest projectile causes a  
126 higher strain rate than the others. The strain rate of the specimen is computed as the derivative of the variation  
127 of strain with time at the midpoint of the sample. Figure 9 shows the values of strain rates obtained when using  
128 different lengths of the same projectile.

## 129 6 Global

130 It can be observed that the 55-cm long projectile impacts at a strain rate equal to 2100s<sup>-1</sup> approximately,  
131 whereas the 40-cm long projectile reaches a maximum value of the strain rate which is in the region of 1500s<sup>-1</sup>  
132 .The 20-cm long projectile impacts around 1000s<sup>-1</sup> . undergoes the maximum strain values. The higher  
133 the strain rate is, the lower its time duration. The strains and strain rates obtained are higher when using the  
134 50-cm long projectile. It can be deduced that if specimens with higher ultimate tensile strength are to be tested,  
135 the impact pressure in the incident bar must increase or otherwise longer projectiles must be used.

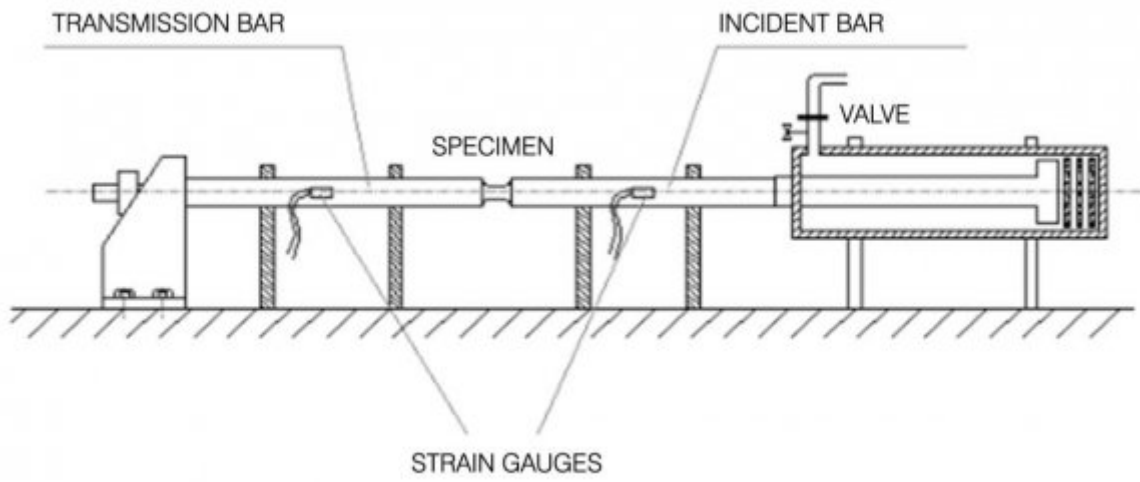
## 136 7 IV. Conclusions



Figure 1: Figure 1 :

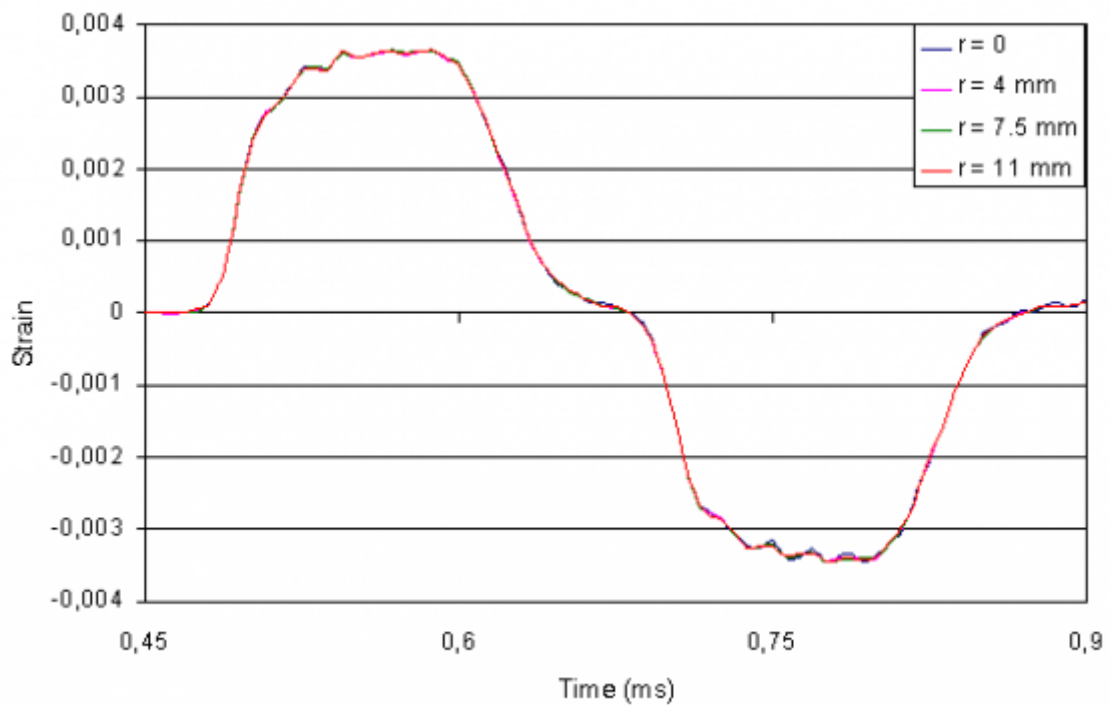


Figure 2: Figure 2 :



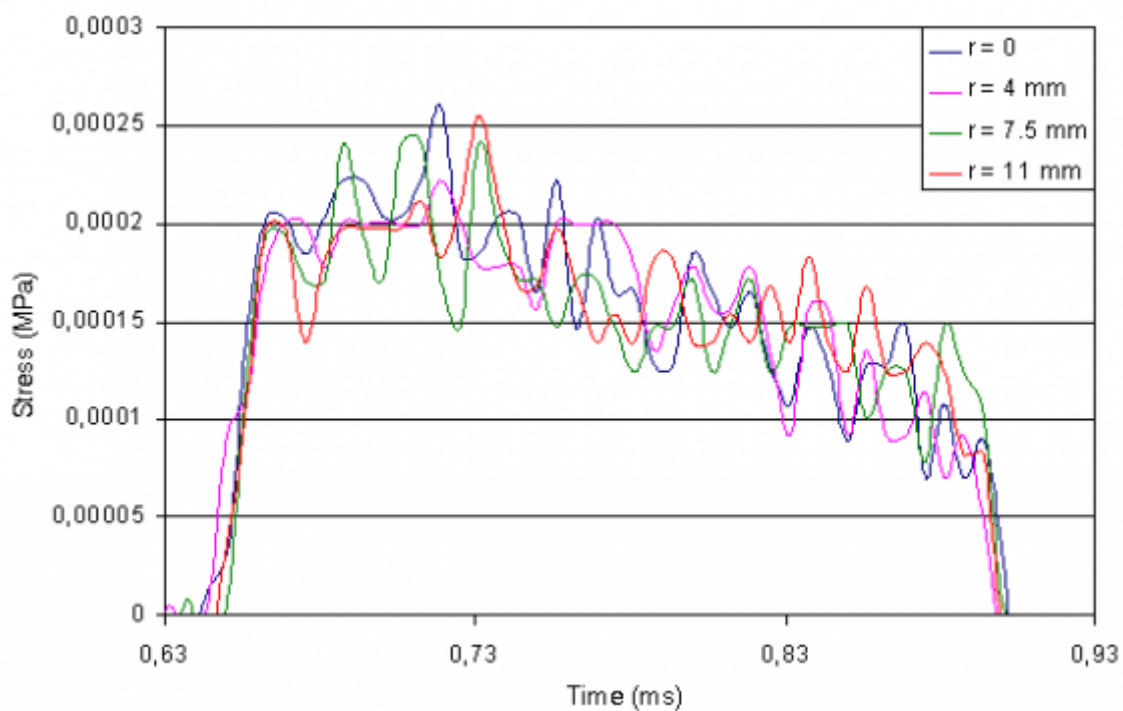
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Figure 3: Figure 3 :



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Figure 4: Figure 4 :



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Figure 5: Figure 5 :

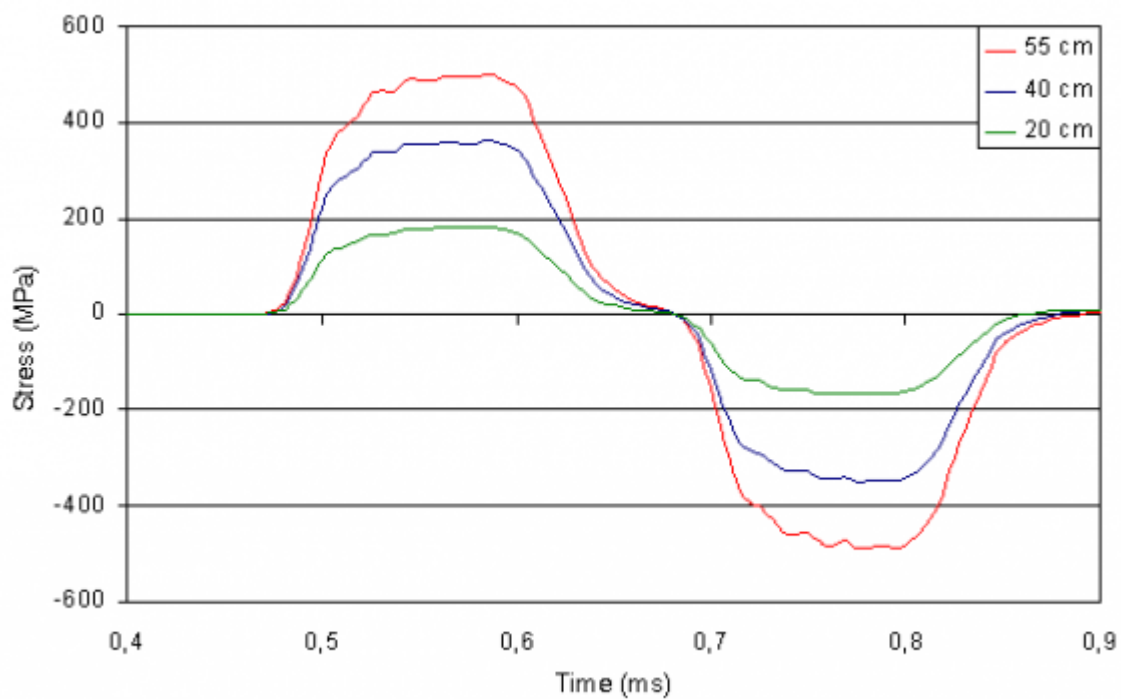
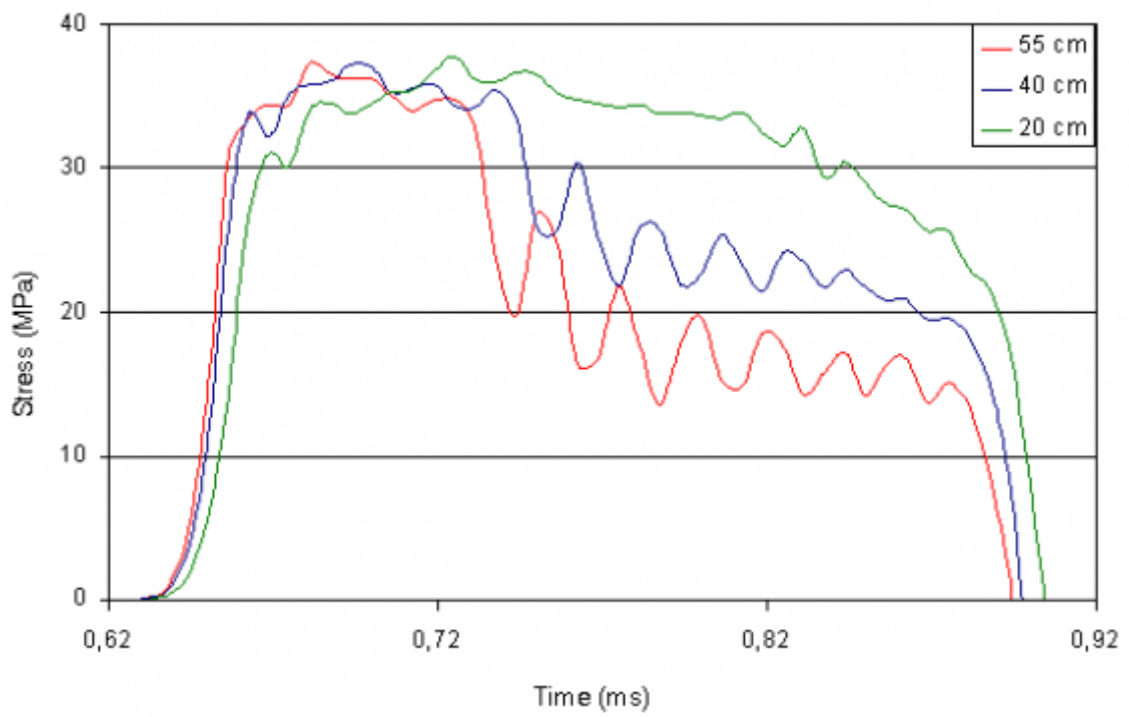


Figure 6: I



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Figure 7: Figure 6 :

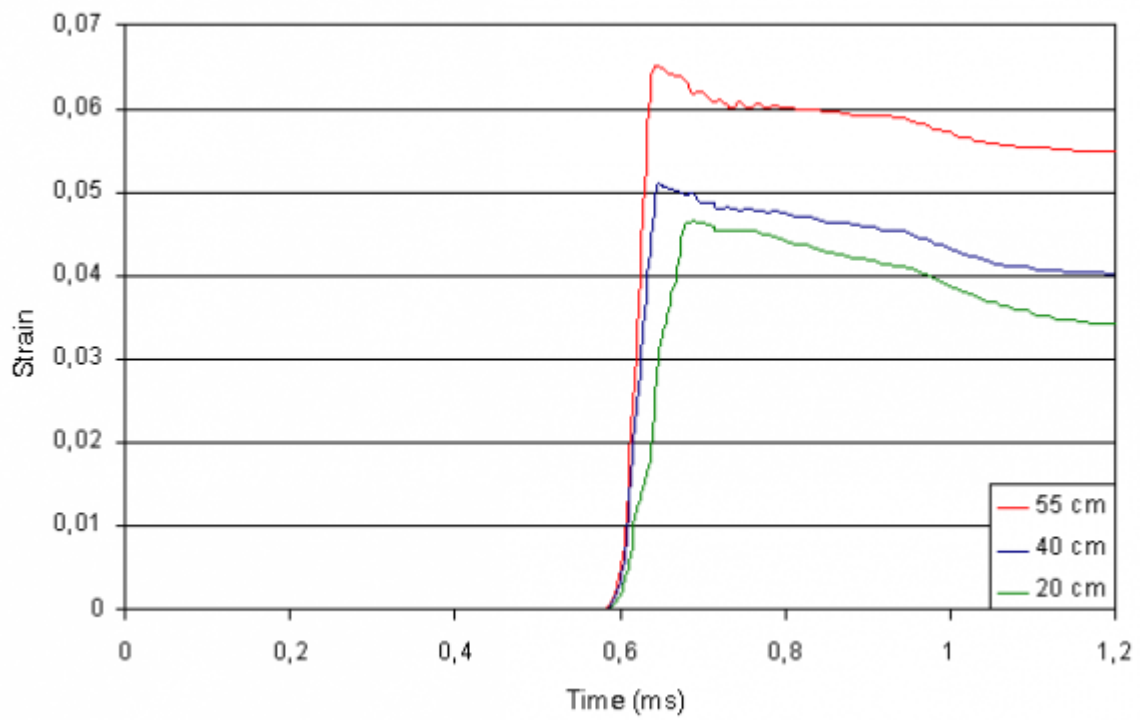
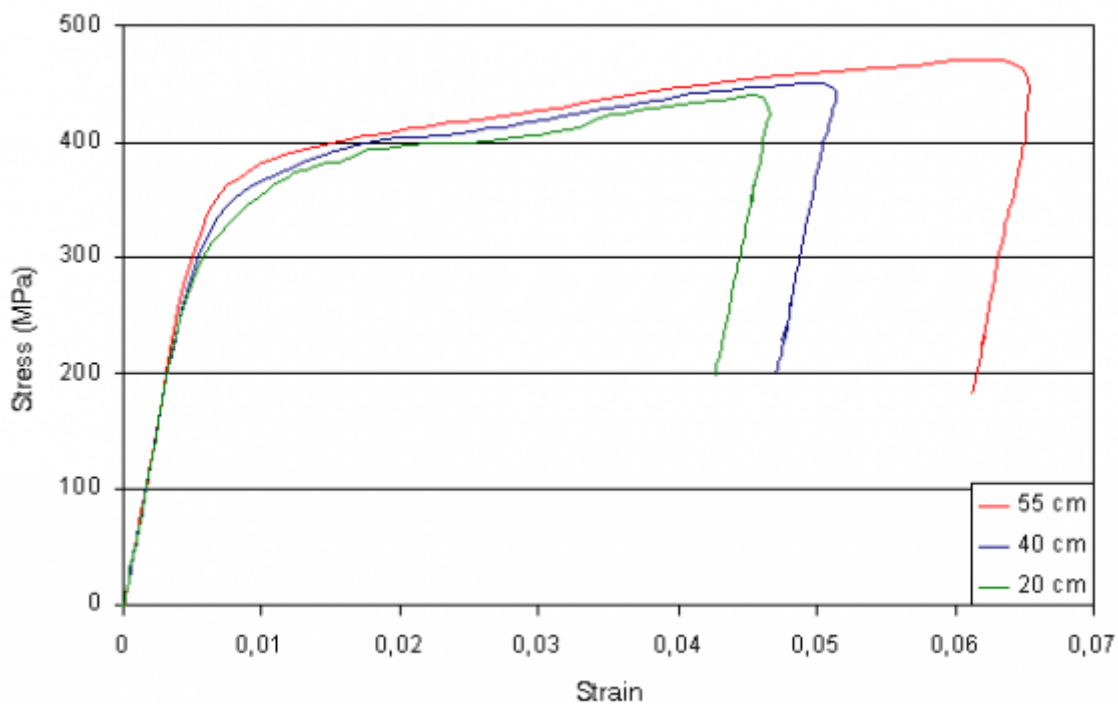


Figure 8:



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Figure 9: Figure 7 :

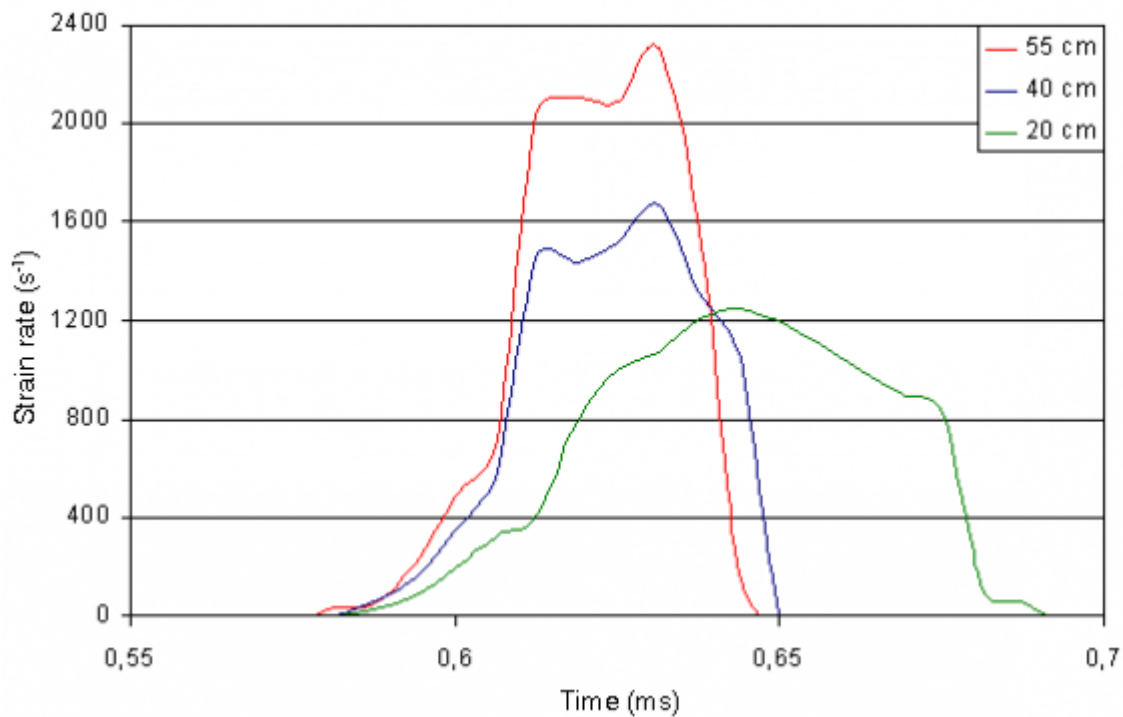


Figure 10: I

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28. ASTM E8/E8M-13a: standard test methods for  
tension testing of metallic materials  
Conshohocken, Novosibirsk: Springer Science+Business Media, 2003.

Hopkinson pressure bar. Compos Sci Technol 2005;

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[Note: © 2015 Global Journals Inc. (US)]

Figure 11:



## .1 V. Acknowledgements

- 137 The authors wish to thank Universidad CEU San Pablo (Madrid, Spain) for facilities and resources provided.  
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 139 [ Society for ExperimentalMechanics ()] , *Society for ExperimentalMechanics* 2001. 4359 p. .  
 140 [Staab and Gilat ()] ‘A direct-tension split Hopkinson bar for high strain-rate testing’. G Staab , A Gilat .  
 141 *ExpMech* 1991. 31 p. .  
 142 [Gerlach et al. ()] ‘A new split Hopkinson tensile bar design’. R Gerlach , C Kettenbeil , N Petrinic . *Int J Impact*  
 143 *Eng* 2012. 50 p. .  
 144 [Harding ()] ‘A tensile testing technique for fiber-reinforced composites at impact rates of strain’. J Harding ,  
 145 WelshL . *J Mater Sci* 1983. 18 (6) p. .  
 146 [Kaiser ()] *Advancements in the split Hopkinson bar test*, M A Kaiser . 1998. Blacksburg, VA. Virginia Polytechnic  
 147 Institute and State University (Master’s Thesis)  
 148 [Dongfang et al. ()] ‘An interruptedtensile testing at high strain rates for pure copperbars’. M Dongfang , C  
 149 Danian , W Shanxing . *J Appl Phys* 2010. 108 (11) p. 114902.  
 150 [Kolsky ()] ‘An investigation of the mechanical properties of materials at very high rates of loading’. H Kolsky .  
 151 *ProcPhysSoc B* 1949. 62 (11) p. 676.  
 152 [Swantek et al.] ‘An optical methodof strain measurement in the split Hopkinson pressurebar’. S Swantek , A L  
 153 Wicks , L Wilson . *Proceedings of IMAC-XIX: a conferenceon structural dynamics*, A L Wicks (ed.) (IMAC-  
 154 XIX: a conferenceon structural dynamics)  
 155 [Rodriguezperez ()] *Analisis y desarrollo de metodologías para la obtención de propiedades mecanicas de*  
 156 *materiales altas velocidades de deformación y a alta temperatura*, J Rodriguezperez . 2002. Universidad  
 157 Complutense de Madrid  
 158 [Gray ()] *Classic split-Hopkinson pressure bar testing*, G T Gray . 2000. Materials Park, OH: ASM International.  
 159 p. .  
 160 [Thakur et al. ()] ‘Dynamic Bauschinger effect’. A Thakur , S Nemat-Nasser , K Vecchio . *Acta Mater* 1996. 44  
 161 (7) p. .  
 162 [Rio et al. ()] *Dynamic tensile behaviour at low temperature of CFRP using a split 14. Van Slycken J. Advanced*  
 163 *use of a split Hopkinson bar setup application to TRIP steels*, T Rio , E Barbero , R Zaera . 2008. Belgium.  
 164 Ghent University (Doctoral Thesis)  
 165 [Verleysen and Degrieck ()] ‘Experimental investigation of the deformation of Hopkinson bar specimens’. P  
 166 Verleysen , J Degrieck . *Int J Impact Eng* 2004. 30 (3) p. .  
 167 [Lindhholm and Yeakley ()] ‘High strain-rate testingtension and compression’. U Lindholm , L Yeakley . *ExpMech*  
 168 1968. 8 (1) p. .  
 169 [Gama et al. ()] ‘Hopkinson bar experimental technique: a critical review’. B A Gama , S L Lopatnikov , J W  
 170 Gillespie . *ApplMech Rev* 2004. 57 (4) p. .  
 171 [Nemat-Nasser et al. ()] ‘Hopkinson techniques for dynamic recovery experiments’. S Nemat-Nasser , J Isaacs ,  
 172 J Starrett . *Proc R SocLond A: Math Phys EngSci* 1991. 435 p. .  
 173 [Yang et al. ()] ‘Interrupted test ofadvanced high strength steel with tensile split HopkinsonBar method’. X Yang  
 174 , X Xiong , Z Yin . *ExpMech* 2014. 54 (4) p. .  
 175 [González-Lezcano and Del Río ()] ‘Numerical analysis of the influence of the damping rings’ dimensions on  
 176 interrupted dynamic tension experiment results’. R González-Lezcano , J Del Río . *J Strain Analysis* 2015.  
 177 [Essa et al. ()] ‘Numerical simulation and experimental study of a mechanism for Hopkinson bar test interruption’.  
 178 Yes Essa , J Lopez-Puente , Perez-Castellanos JI . *J StrainAnal Eng Des* 2007. 42 (3) p. .  
 179 [Verleysen et al. ()] ‘Numerical study of the influence of the specimen geometry on Split Hopkinson bar tensile  
 180 test results’. P Verleysen , V Benedict , T Verstraete . *Lat Am J Solids Struct* 2009. 6 (3) p. .  
 181 [Lezcano et al.] *Numericalanalysis of interruption process of Global Journal of Researches in Engineering ( )*  
 182 *Volume XV Issue IV Version I*, R Lezcano , Essa Yes , J Perez-Castellanos .  
 183 [Pe´rez-Mart?´n and Galvez ()] ‘On the loadingratedependence of the Al 7017-T73 fractureinitiationtoughness’.  
 184 M J Pe´rez-Mart?´n , Erice , B Galvez , F . *Procedia Mater Sci* 2014. 3 p. .  
 185 [Khlif et al. ()] ‘Polypropylene tensile test under quasi-static and dynamic loading’. M Khlif , N Masmoudi , C  
 186 Bradai . *Materials science and technology conference and exhibition (MS&T)*, 2012.  
 187 [Resnyansky ()] ‘Study of influence of loading method onresults of the split Hopkinson bar test’. A Resnyansky  
 188 . *Structural Failureand Plasticity (IMPLAST)*, 2000. p. .  
 189 [Nicholas ()] ‘Tensile testing of materials at high-rates of strain’. T Nicholas . *ExpMech* 1981. 21 (5) p. .  
 190 [Hamouda and Hashmi ()] ‘Testing of composite materials at high rates of strain: advances and challenges’. A  
 191 Hamouda , M Hashmi . *J Mater Process Technol* 1998. 77 (1-3) p. .  
 192 [Albertini and Montagnani ()] ‘Wave-propagation effects in dynamic loading’. C Albertini , M Montagnani .  
 193 *NuclEng Des* 1976. 37 (1) p. .  
 194