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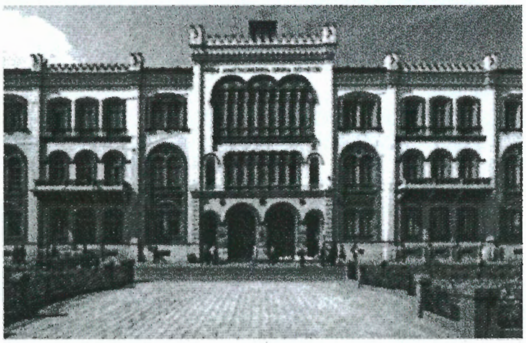

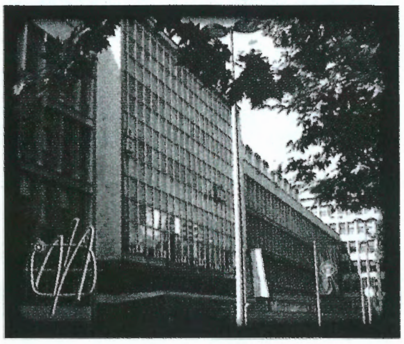

Proceedings of the 29th Danubia-Adria-Symposium

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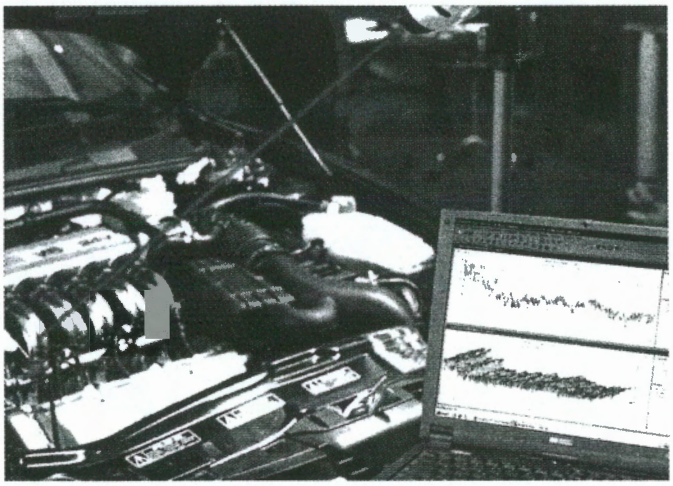

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Preface

Welcome to the 29th Danubia-Adria Symposium dealing with methods and applications in experimental mechanics as means for verifying quality of structures from the point of view of integrity, service and residual life, and technical safety. The DA Society has the objective to promote experimental mechanics, covering all aspects from the development to applications of the methods for quality improvement of processes and products to the development of a new model of education in experimental mechanics. To achieve this purpose, the Society aims to encourage exchanges of teachers, researches and students between Universities and other technical and scientific institutions.

Danubia-Adria Symposiums on Advances in Experimental Mechanics has a long tradition, since 1984. The 29th Symposium in Belgrade presents continuation of this tradition. Serbia joints to Danubia-Adria Society in 2008 year and got active member in organization and participation of DAS which take place every year in one of DA member country. This year Belgrade has been chosen as the Conference venue and we offering the hospitality for our Symposium. Serbian society for mechanics is the member of DA Society and University of Belgrade, Faculty of Mechanical Engineering is executive organizer of DAS-29.

University of Belgrade has been funded at the end of 19th century and Faculty of Mechanical Engineering in the mid of 20th century. Today our Faculty has more than 16 hundreds active students at all three levels, Bachelor, Master and PhD in relation of 3+2+3 nominal education years. At the master level education process contains about 20 branches (education modules) of engineering (not mechanical only). For majority of these branches experiments in research and in education is the main tool.

This year's DAS has received 111 accepted submissions from 12 countries (Austria-7, Croatia-14, Czech Republic-4, Germany-3, Hungary-9, Italy-5, Poland-13, Romania-6, Slovakia-6, Slovenia-4, Bosnia & Herzegovina-1, Serbia-39). The Program Committee selected 12 papers for podium presentation and 99 papers for poster presentation. I believe that the present Symposium, with its aim to exchange ideas concerning the search for new models, design solutions, and manufacturing technologies, will constitutive the next, very important step in the development of experimental mechanics.

On behalf of the Organizing Committee of the 29th DANUBIA-ADRIA Symposium on Advances in Experimental Mechanics, organizers wish a worm WELCOME to all the participants in Belgrade, and hope that all the guests will have a pleasant time in Serbia.

Chairman of 29th DAS on Advances in Experimental Mechanics

M. Ognjanović

Milosav OGNJANOVIĆ

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COMPARATIVE RESULTS OF WAGON STRESSES OBTAINED BY MEASURING WITH STRAIN GAUGES AND STRESSES OBTAINED BY FEM CALCULATION
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SOME ASPECTS IN DESIGN OF SPLIT HOPKINSON TENSION BAR

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1. Introduction

This paper represents an author's effort in design and building of Split Hopkinson Bar.

In last few years, investigations of influence of impulse loading on constructions become important than ever. Spectrums of industry in which we can find examples of impulse loading are very wide and involve automotive industry, aerospace industry, sheet metal forming, metal cutting industry and many others. However, impulse loading is most presence in military industry in fields like ballistics, aircraft integrity, mine resistance of vehicles and others. Performing of experiments is very complicate and very expensive, so one of the first steps in design process is using numerical simulations.

Due to existing computer codes, it is necessary to appropriate define characteristics of materials not only the stress-strain response, but also the accumulation of damage and the parameters of failure. Further, it is well known that most material shows significant change in mechanical response for different strain rates and temperatures. Understanding of this is very important in design process of constructions and its components.

Properly definitions of constitutive relations that best describe particular material or class of materials is basic problem in numerical simulations. Defining the general model of material constitutive relations for wide range of material behavior is very difficult, so this relations cover only certain range of strain rates in which they describe material more authentic.

One of the basic forms of constitutive relations is given by equation:

$$\sigma = f\left(\varepsilon, \dot{\varepsilon}, T\right)$$

where ε is strain, $\dot{\varepsilon}$ is strain rate and T is temperature. Defining the parameters from equation 1.1 can be done only by experiments. For different strain rate, different methods were developed. On Fig. 1 is present general classification of strain rate regimes.

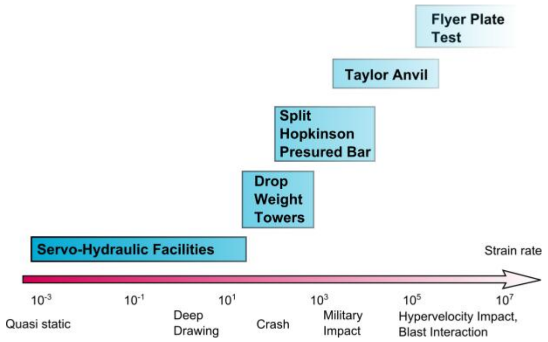

Fig. 1: Dynamic aspects of mechanical testing [1]

Strain rates from 10^{-3} s or higher belongs to high strain rates for which one effects of inertia, thermal and wave propagation become important for material behavior. Also, at high strain rates, thermodynamics influence is present, because of transition from isothermal to adiabatic conditions.

2. High strain-rate test – Split Hopkinson Tensile Bar

One of the most widely used set-ups for high strain-rate material testing is Split Hopkinson Bar. It was developed by Hopkinson as single bar facility and second bar was added by Kolsky, today known as Split Hopkinson Pressure Bar (SHPB), or just Kolsky. In meanwhile, there are various variations of the Hopkinson-Kolsky bars which include compressive, tensile and torsion loading form of specimens. However, in standard quasistatic material testing, tensile tests are far more common than compression tests, so this has motivated the development of Split Hopkinson Tension Bars (SHTB). Fig. 2 shows concept overview of SHTP and Fig. 3 shows CAD model of SHTP.

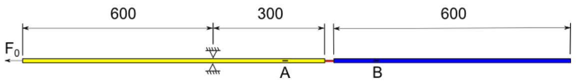

Fig. 2: Overview of Split Hopkinson Tension Bar

Fig. 3: CAD model of Split Hopkinson Tension Bar

In SHTB one bar act as pre-stressed bar (tension device) for energy storage and in same tame as incident bar. After release of blocking device, Fig. 4 [2], an incident tension wave propagates through incident bar. At interface between incident bar and specimen, wave is partly transmitted into the specimen and partly reflected back into the incident bar. The transmitted component travels through the specimen and at interface to the transmitter bar, again, a partly is transmitted and partly is reflected. The derivation of stress-strain relations from the set-up uses strain signals measured with stain gages on the incident bar and on the transmitter bar (point A and point B on Fig. 2), respectively.

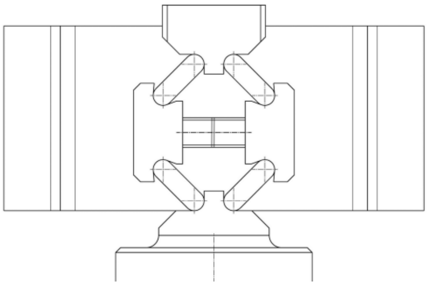

Fig. 4: Blocking device

In SHTB stress, strain and strain rate in specimen can be determined by use of one-dimensional stress wave theory and data collected from two strain gages, on incident and transmitter bar. The expression for the average specimen stress is

$$\sigma_{AVG}(t)=\frac{ED_{BAR}^2}{D_s^2}\varepsilon_T(t)$$

where E is elastic modulus, D_{BAR} is diameter of incident and transmitted bar, D_s is diameter of specimen and ε_T is measured strain at transmitted bar. Strain in specimen is

$$\varepsilon_s(t)=-\frac{2C_0}{L}\int\varepsilon_R(t)dt$$

where L is specimen length, $C_0=\sqrt{E/\rho}$

ε_R is reflected stain. Strain rate in specimen is

$$\frac{d\varepsilon_s}{dt}=-\frac{2C_o}{L}\varepsilon_R$$

3. Numerical model

There were two separate numerical models simulated. First model consists of incident, transmitted bars and specimen. Second model represent carried construction which comprise pre-stressed part of incident bar.

Numerical simulations were done in LS-DYNA as a general-purpose explicit/implicit finite element code for analyzing the nonlinear dynamic response [3, 4]. Both, incident and transmitter bar were modeled with a diameter of 10 mm, with a length of 9000 mm and 6000 mm, respective. The standard specimen was used, Fig. 5.

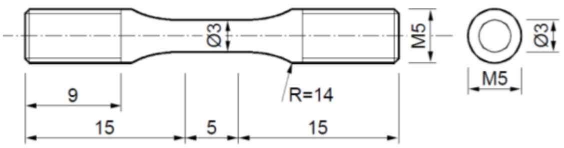

Fig. 5: Standard test specimen

An assembly that contains all parts (bars, tension device and specimen) was modeled using three-dimensional solid 8-node elements, Fig. 6 and Fig. 7. A perfect contact between the incident bar and tension device was assumed and the frictional forces were ignored. Reference points acting as gauges were placed on input and output bars, with the main purpose to collect incident, transmitted and reflected waves. Distance from specimen to reference point on both, transmitter and incident, bars are the same, 600 mm.

Isotropic elastic material MAT_001 was used to simulate the bars. MAT_003 in LS-DYNA is suited to model isotropic and kinematic hardening plasticity with the option of including rate effects and it was used to simulate specimen material response. This model implies a bilinear stress/strain curve.

Fig. 6: Finite element model of specimen

Characteristics of the specimen and bar materials are given in Tab 1. The materials are Steel and Aluminum, respectively.

Physical properties	Bars	Specimen
	Steel	Aluminum
Density, ρ (kg/m^3)	7.83E+3	2.690 E+3
Yield Strength, σ_y (Pa)	N/R	335 E+06
Elastic Modulus, E (Pa)	2.07 E+11	7.308 E+10
Poisson’s Ratio, ν	0.3	0.33
Tangent Modulus, Et, (Pa)	N/R	645.7 E+06
Failure Strain, fs	N/R	0.54

Tab. 1: Material properties

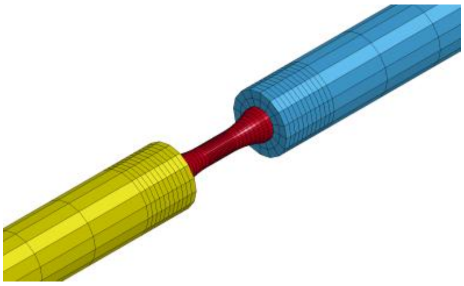

Fig. 7: Finite element model of specimen and bars in connection

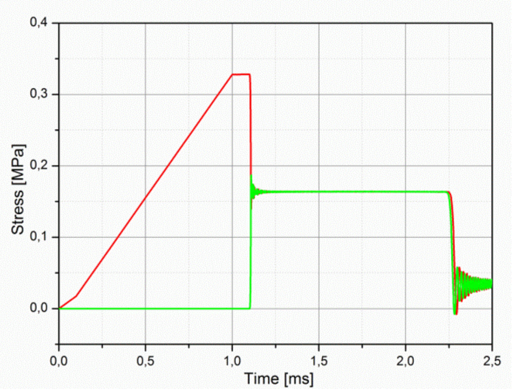

Fig. 8: Tension diagram of pre-stressed bar (red) and releasing diagram (green)

Fig. 8 represent pre-stressed diagram (357 MPa) of incident bar that correspond to 10 mm displacement of tension device. Also, after releasing incident bar at blocking device, half part of pre-stressed wave (178 MPa) travel to specimen and half to tension device.

Measured strains at reference points, are represented on Fig. 9. Because of "noise" nature of strain curve, filtering option was used that enabled damping of such oscillations by removing the high frequency vibrations. In this case, cut-off frequency that was used has value smaller than half of the sampling frequency end it was set at 5 kHz.

Smallest element located in specimen, was used for controlling of time step and his value was 0.13e^{-4} ms. Incident stress wave reaches the specimen for 0.58 ms and travel 0.0672 mm along the bar for each time step [4]. Of course, it remains lower than the smallest element (0.095 mm) that was used for time step determination.

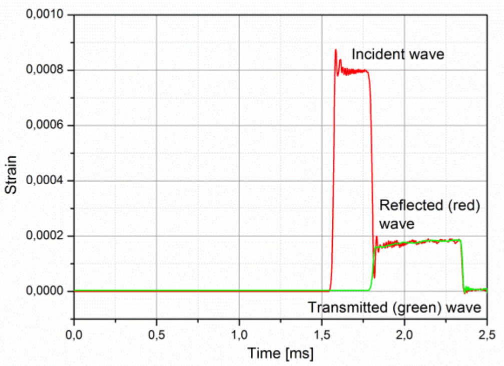

Fig. 9: Incident, transmitted and reflected wave of strain

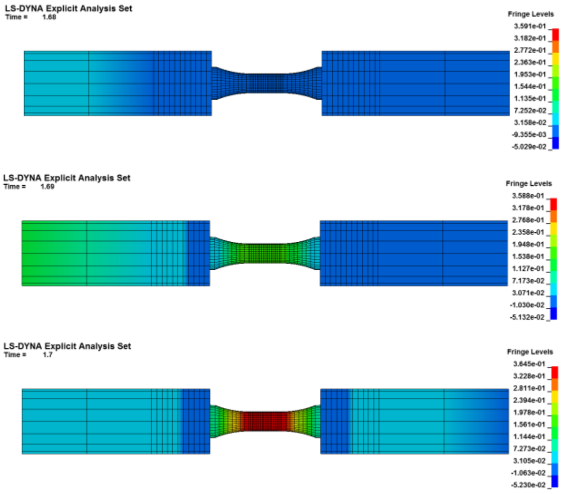

Fig. 10: Stress distributions after reaching the specimen

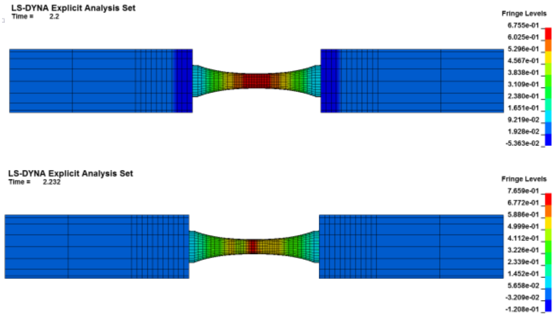

Fig. 11: Stress distributions before fracture

Stress distributions after reaching the specimen and just before fracture, are represented on Fig. 10 and Fig. 11, respective.

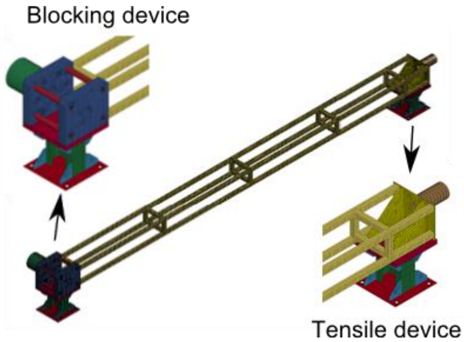

Fig. 12: Carrying construction

In order to fully develop the SHTB in design process, analysis of carrying constriction was done, Fig. 12. Blocking device was clamped and tensile device have constrain in lateral directions. After releasing the blocking device, reactions of support were analysis. Reactions forces are on Fig. 13 and Fig. 14.

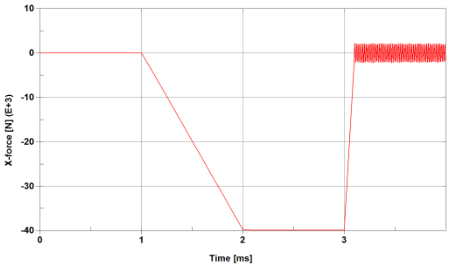

Fig. 13: Longitudinal reaction at blocking device

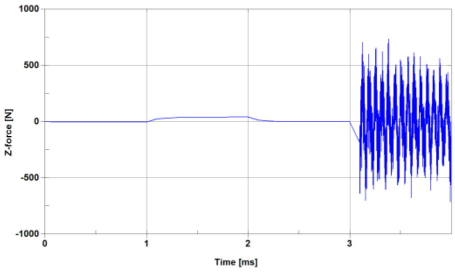

Fig. 14: Lateral reaction force on blocking device

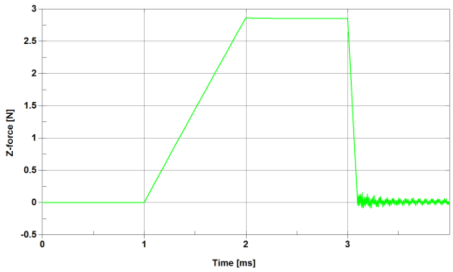

Fig. 15: Lateral reaction force on tension device

4. Conclusions

First step, as most natural, in development of Split Hopkinson Tension Bar was to do some numerical simulation. After those simulations, we are able to fully understand the entire process and to put some authentic solutions. This paper represent some shortly considerations in design process of SHTB.

5. Acknowledgements

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