Journal of KONES Powertrain and Transport, Vol. 19, No. 2 2012

NUMERICAL SIMULATION OF DYNAMIC WELD COMPRESSION

Wiesław Barnat, Marek Kordys

Military University of Technology
Department of Mechanics and Applied Computer Science
Kaliskiego Street 2, 00-908 Warsaw, Poland
tel.: +48 22 683-72-01, +48 22 683-73-48, fax: +48 22 683-94-61
e-mail: wbarnat@wat.edu.pl, mkordys@wat.edu.pl

Wojciech Moćko

Polish Academy of Sciences
Institute of Fundamental Technological Research
Pawinskiego Street 5B, 02-106 Warsaw, Poland
tel.: +48 22 826-12-81, fax: +48 22 826-98-15
e-mail: wmocko@ippt.gov.pl

Paweł Dybcio, Robert Panowicz

Military University of Technology
Department of Mechanics and Applied Computer Science
Kaliskiego Street 2, 00-908 Warsaw, Poland
tel.: +48 22 683-72-01, +48 22 683-73-48, fax: +48 22 683-94-61
e-mail: pdybcio@wat.edu.pl, rpanowicz@wat.edu.pl

Abstract

The article presents some numerical results and experimental validation of Split Hopkinson pressure bar (SHPB) tests for welded S40NL steel. The goal of this research is to define material constants for modelling it in FEM. Steel was tested with Charpy impact test to determine properties of material. Next, the joint for welding was prepared. It was welded with electric arc welding method (MAG) with flux-cored wire. Hopkinson bar test is well-known experiment method used to determine material properties at high strain rates. The tests were performed in Institute of Fundamental Technological Research. Material properties for Johnson-Cook material model were obtained. Comparison between experimental results taken in quasi-static conditions and dynamic conditions proves that the behaviour of materials in those two states is quite different. Results from one type of loading condition cannot be used to create a realistic model of material when it is loaded dynamically. Numerical simulation of Hopkinson bars was performed on cylindrical model with known length and accelerated to high speed in direction of incident bar. For the purpose of the simulation, a Finite Element Code LS-DYNA was used. It allows simulation of dynamic response of SHPB system. The results show quite good agreement. The model can be used to simulate weld performance under high strain rate.

***Keywords**: Split Hopkinson Pressure Bar, SHPB, welding, weld*

1. Introduction

Recent development of manufacturing technologies, designing methods, and rising pressure to optimize elements and structures, require more detailed knowledge and calculation skills to predict materials behaviour in high-speed load conditions. New measuring techniques invented last year's allows us to measure the processes in the material when loaded with high speed.

Designers require an in-depth understanding of dynamic responses of welded joints for reliable designing all welded parts. There has been done a lot of modelling for static loaded parts but not much is known of welded joints response and its influence on the whole construction at various environmental conditions.

As far welding is one of the most common used techniques for joining metals and is widely used by the industry. The purpose of research described in this paper is to compare different material model descriptions for modelling such kind of joints in FEM.

2. Dynamic compression testing using Split Hopkinson Pressure Bar

Hopkinson bar test is well-known experiment method used to determine material properties at high strain rates.

Hopkinson bar test consists of two long and slender bars (incident and transmitting bar) of high resistance to plastic deformation. Between those two horizontally placed bars is placed a small cylindrical specimen of tested material with much lower resistance to deformation. Third bar (termed projectile) is fired with a high velocity to hit one of the free ends of the incident bar. This impact produces elastic wave σ_1, which propagates with high speed C_0 along the incident bar. This quantity depends on density ρ of the bar material and its Young modulus E.

$$C_0 = \sqrt{\frac{E}{\rho}} \,. \tag{1}$$

Intensity of the incident wave σ_1 is proportional to the projectile speed V_p.

$$\sigma_1 = \frac{\rho_0 C_0 V_p}{2} \,. \tag{2}$$

When the pulse arrives to the end of incident bar (where the specimen is placed) the pulse is partially reflected and it goes back through the incident bar in the opposite direction. The rest of the wave is transmitted to the specimen where it is again reflected from the specimen ends several times. When wave reaches the specimen it causes elastic and plastic deformation of specimen.

First reflection in specimen is causing wave propagation to transmitter bar. Next reflection transmits wave again into incident bar. Strain gauges placed on incident and transmitter bars are measuring impulses during wave propagation.

Knowing character of these three elastic waves and the relative displacement of the specimen faces $\Delta U(t)$, the average nominal strain of the specimen may be obtained.[2]

$$\varepsilon(t) = \frac{\Delta U}{L_0} = \frac{U_2(t) - U_1(t)}{L_0} \,, \tag{3}$$

$$\varepsilon(t) = \frac{C_0}{L_0} \int_0^t \left[\varepsilon_{transmitted}(t) - \varepsilon_{incident}(t) - \varepsilon_{reflected}(t) \right] dt \,, \tag{4}$$

where: $U_2(t), U_2(t)$ - displacements of the specimen faces

Forces in input and output bars can be described by the equations[2]:

$$\begin{aligned} F_{in}(t) &= A_0 E \left[\varepsilon_{incident}(t) + \varepsilon_{reflected}(t) \right], \\ F_{out} &= A_0 E \left[\varepsilon_{transmitted}(t) \right], \end{aligned} \tag{5}$$

where: A_0-cross-section of Hopkinson pressure bar.

Those forces equilibrium in the bar have to be checked before performing experiment so we have:

$$\varepsilon_{incident}(t) + \varepsilon_{reflected}(t) = \varepsilon_{transmitted}(t) \,. \tag{6}$$

When the forces on the both sides of the specimen are known it is possible to define the average stress level imposed to the tested specimen[2].

$$\sigma(t) = \frac{F_{in}(t) + F_{out}(t)}{2A_S} = \frac{A_0 E\left[\varepsilon_{incident}(t) + \varepsilon_{reflected}(t) + \varepsilon_{transmitted}(t)\right]}{2A_S}, \tag{7}$$

where A_s -cross-section of specimen.

According to above equations it is possible to calculate stresses, strains and strain rates[2]:

$$\sigma(t) = E_b \left(\frac{\phi_{bars}}{\phi_{specimen}} \right)^2 \left| \varepsilon_{transmitted}(t) \right|, \tag{8}$$

$$\varepsilon(t) = \frac{2C_0}{L_0} \int_0^t \left| \varepsilon_{reflected}(t) \right| dt, \tag{9}$$

$$\dot{\varepsilon}(t) = \frac{2C_0}{L_0} \varepsilon_{reflected}(t). \tag{10}$$

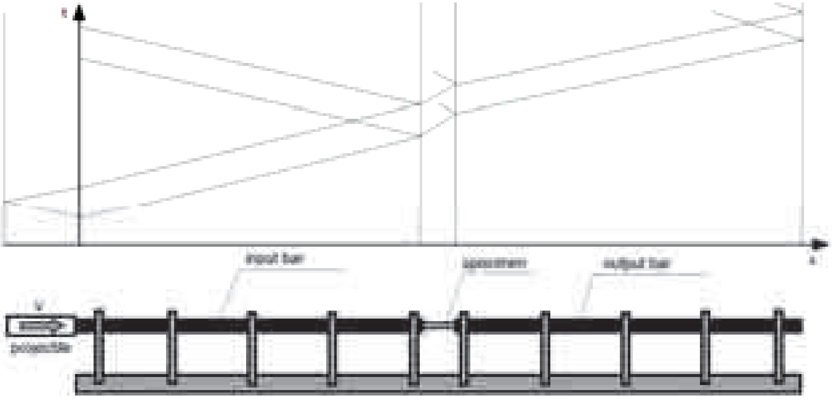

Fig. 1. Scheme of Hopkinson bar apparatus and wave propagation diagram

To avoid of plastic deformation of incident and transmitter bar are made of special material with high wave resistance.

3. Modelling

Model for calculations was created in SolidEdge and exported to HyperMesh for meshing.

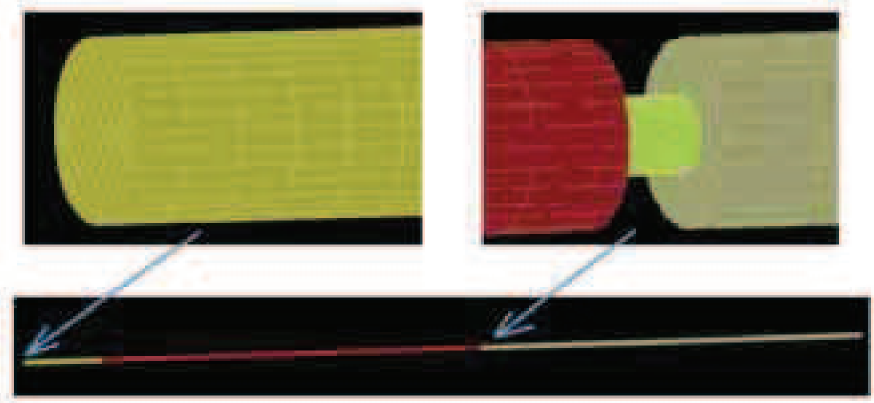

Fig. 2. Geometry and mesh size for calculated model

Model consists 4 parts:

1) cylindrical projectile,
2) and 3) Incident and transmitter bar,
4) Specimen.

Tab. 1. Parts dimensions

Dimension	Length [m]	Diameter [m]
Projectile	0.4	0.02
Incident and transmitter bars	2	0.02
Specimen	0.01	0.01

The bars during all calculations were considered as isotropic solid and elastic material (No. 1) card was defined for them. The friction effect was not considered.

Tab. 2. Mechanical properties of the incident and transmitter bars and projectile

Mechanical properties	
Density ρ [kg/m^3]	7830
Elastic modulus E [GPa]	207
Poisson ratio ν	0.3

Finite element simulation of the Hopkinson Bars was performed using commercial software LS-DYNA. The varying parameter for the simulation was specimen material.

The first calculated case was specimen with defined material type as Elastic. Parameters were the same like for bars (Tab. 2).

Fig. 3. Wave propagation through initial bar in t=0.15999ms

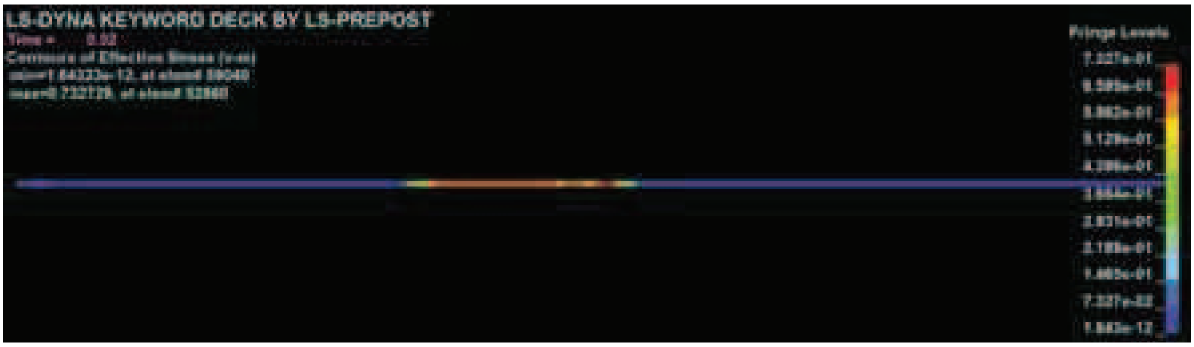

Fig. 4. Wave propagation through initial bar in t=0.32ms

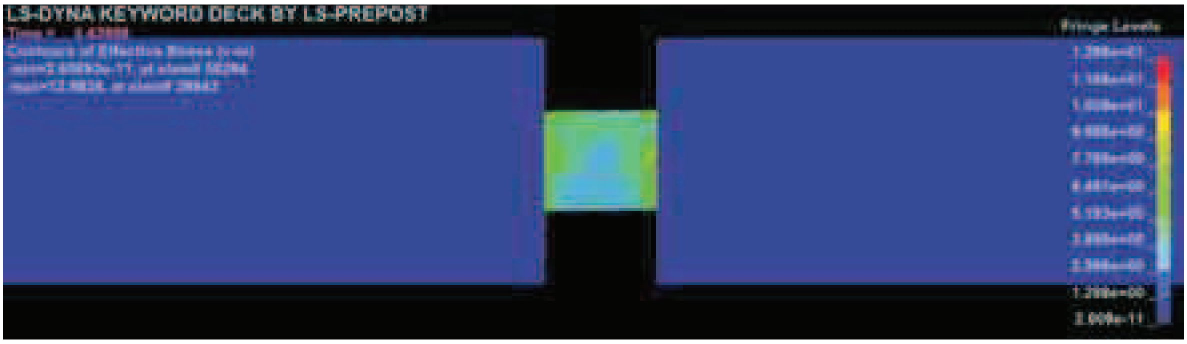

Fig. 5. Wave propagation through isotropic elastic specimen in t=0.43998ms

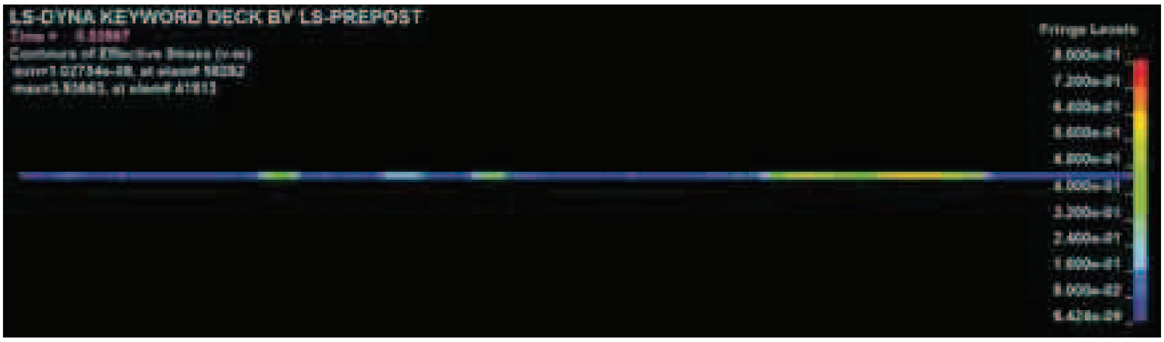

Fig. 6. Wave propagation through the transmitter bar and reflected wave in the initial bar in t=0.53997ms

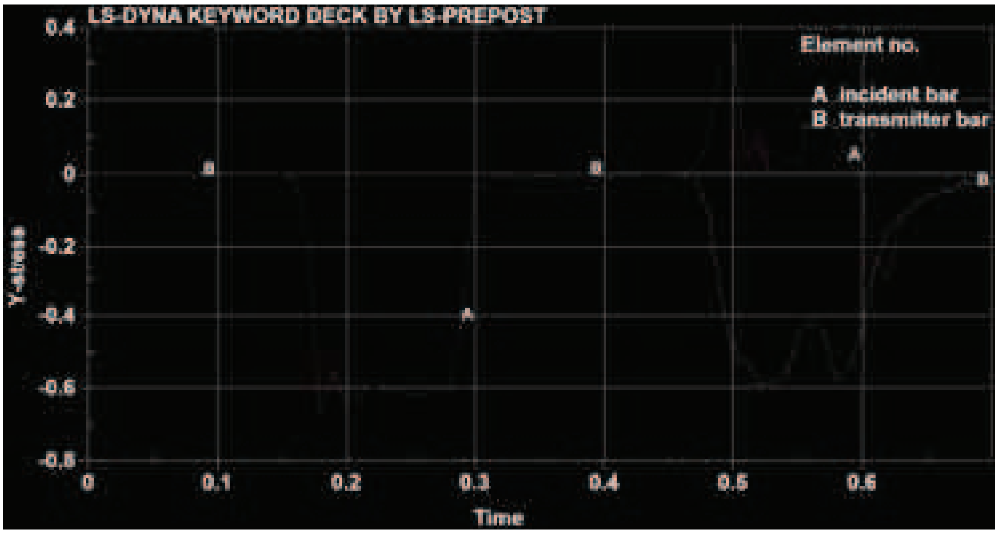

Fig. 7. Representation of calculated incident, reflected and transmitted pulses.

In the second calculated case the specimen's material was defined as simplified Johnson-Cook.

Tab. 3. Material parameters for defining Simplified Johnson-Cook material

Mechanical properties and parameters– simplified J-C	
Density ρ [kg/m^3]	7830
Elastic modulus E [GPa]	207
Poisson ratio ν	0.3
A [MPa]	350
B [MPa]	700
n	0.2
c	0.0047

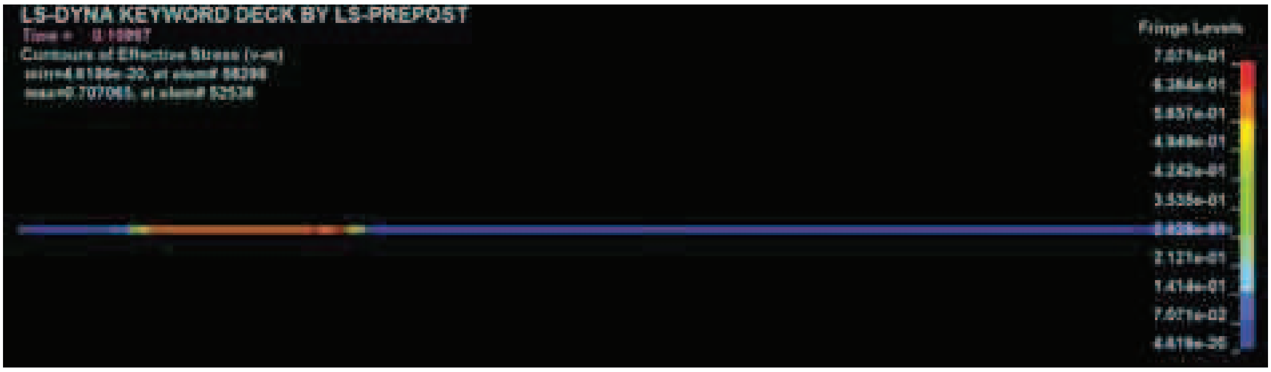

Fig. 8. Wave propagation through initial bar in t=0.15997ms

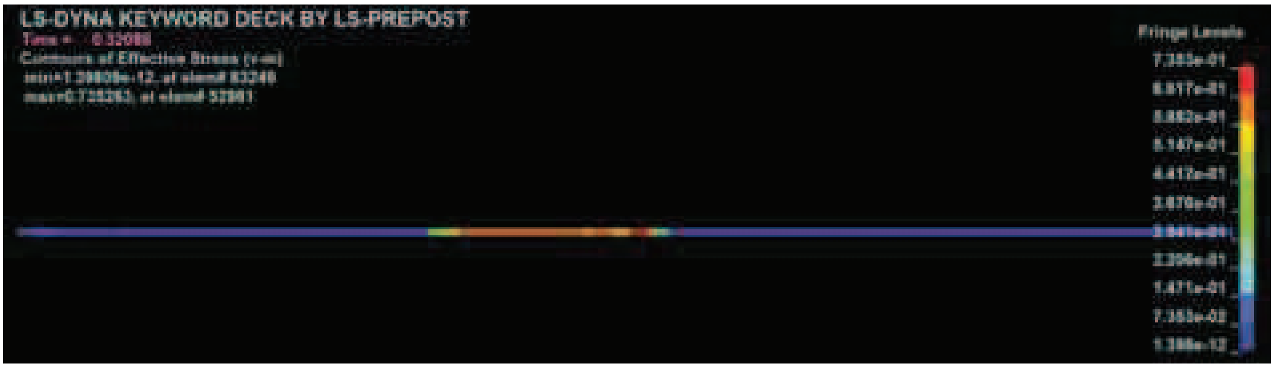

Fig. 9. Wave propagation through initial bar in t=0.32098ms

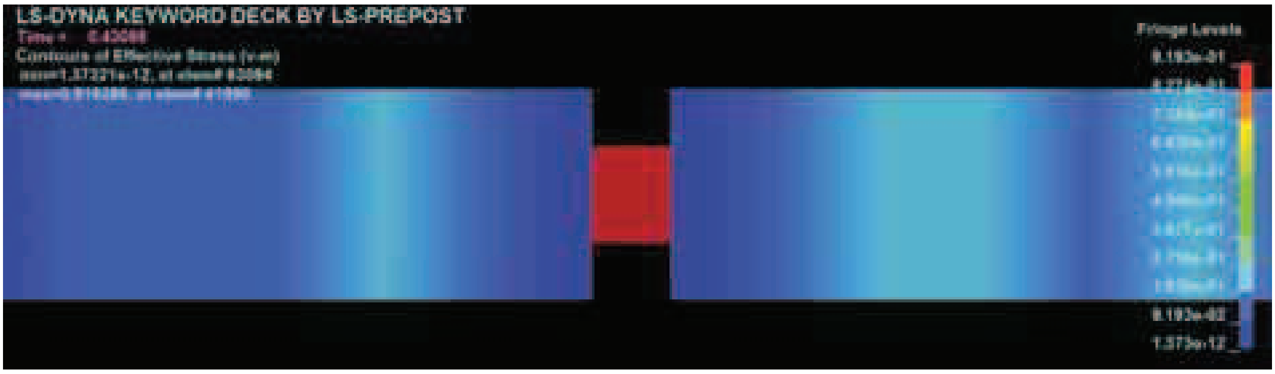

Fig. 10. Wave propagation through specimen in t=0.43098ms

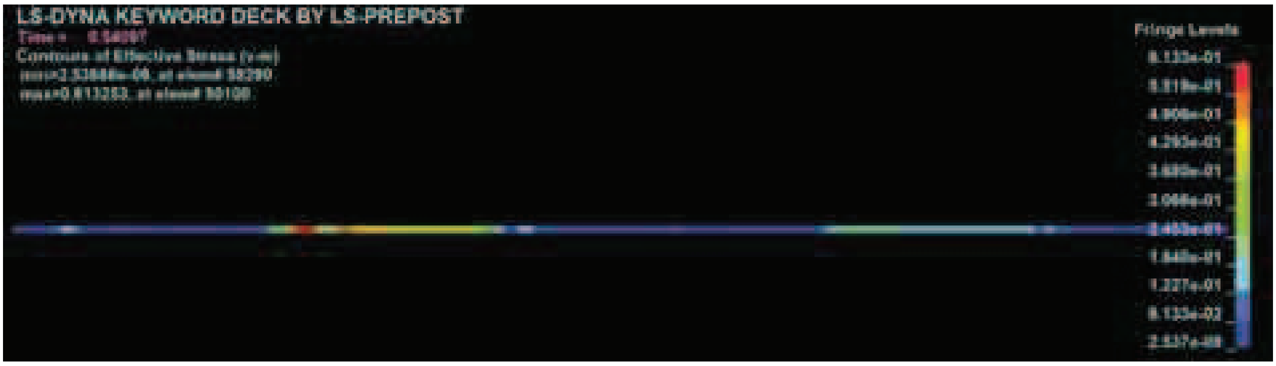

Fig. 11. Wave propagation through transmitter bar and reflected wave in the initial bar in t=0.54097ms

In third case the Johnson-Cook material was defined and Gruneisen Equation Of State (EOS) formulated for specimen.

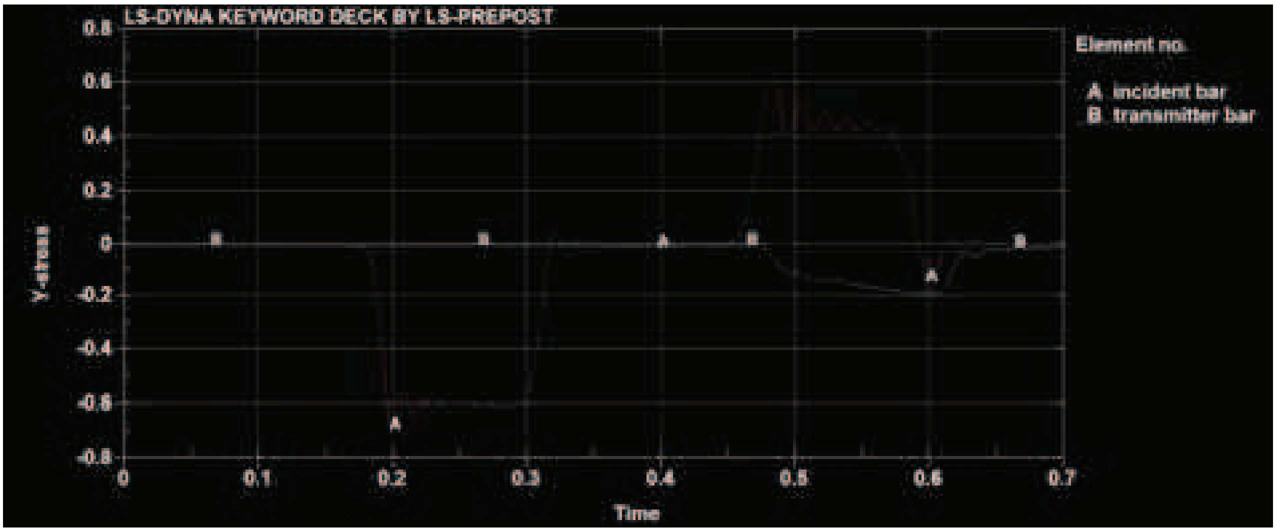

Fig. 12. The incident, reflected and transmitted pulses calculated with LS-DYNA

Tab. 4. Material parameters for defining Johnson-Cook material

Mechanical properties and parameters– J-C	
Density ρ [kg/m^3]	7830
Elastic modulus E [GPa]	207
Shear modulus [GPa]	76
Poisson ratio ν	0.3
A [MPa]	350
B [MPa]	700
N	0.2
C	0.0047
M	0.5
Melting temperature TM	1800
Room Temperature TR	293
Specific Heat CP	460

Because the Johnson-Cook model needs Equation of state Gruneisen EOS was defined to describe the behaviour of specimen material.

Tab. 5. Constants for Gruneisen EOS

Equation of State constants -Gruneisen	
C [m/s]	4570
S1	1.49
S2	0
S3	0
Gamma0	1.9299
A	0.5
Initial internal energy E0	0

Fig. 13. Wave propagation through initial bar in t=0.15998ms

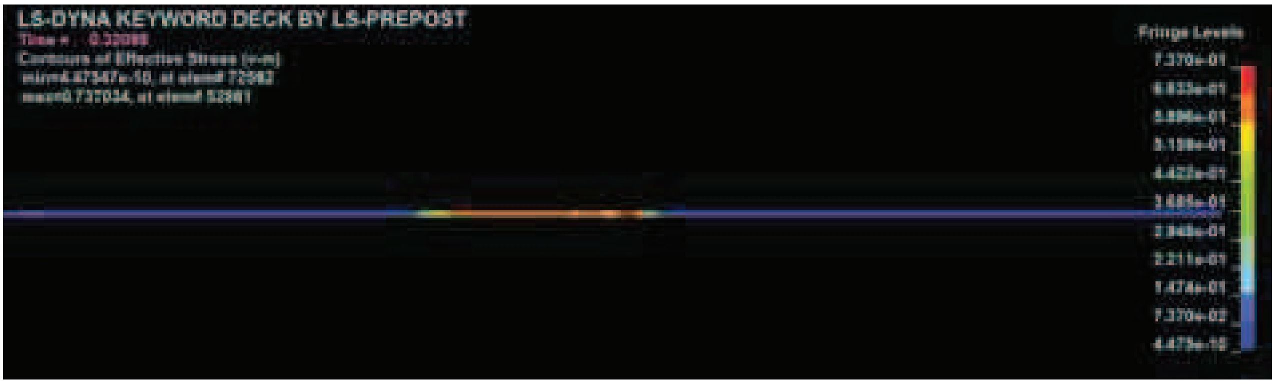

Fig. 14. Wave propagation through initial bar in t=0.32098ms

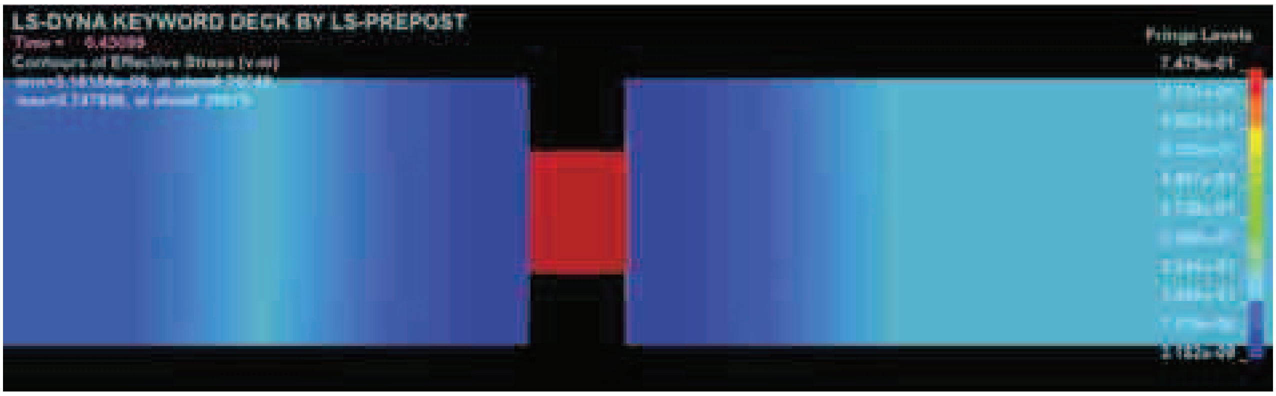

Fig. 15. Wave propagation through specimen in t=0.43099ms

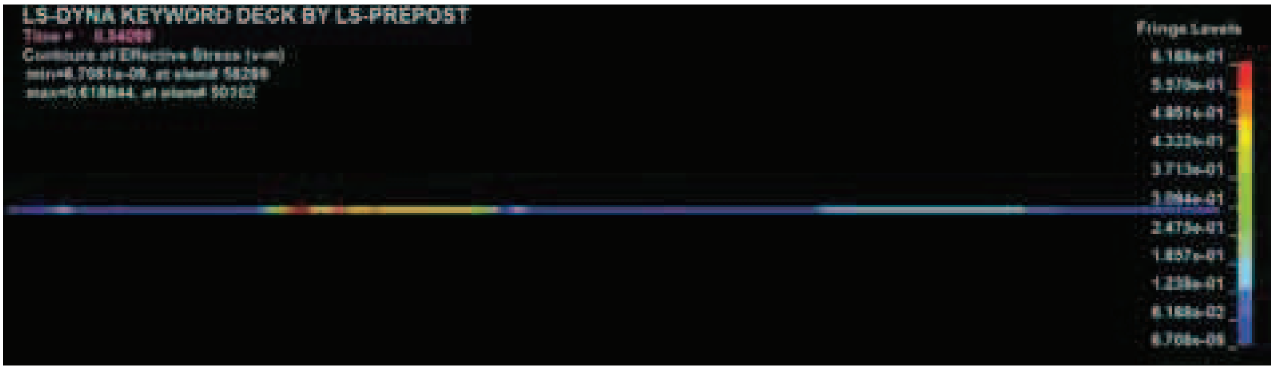

Fig. 16. Wave propagation through transmitter bar and reflected wave in initial bar in t=0.54099ms

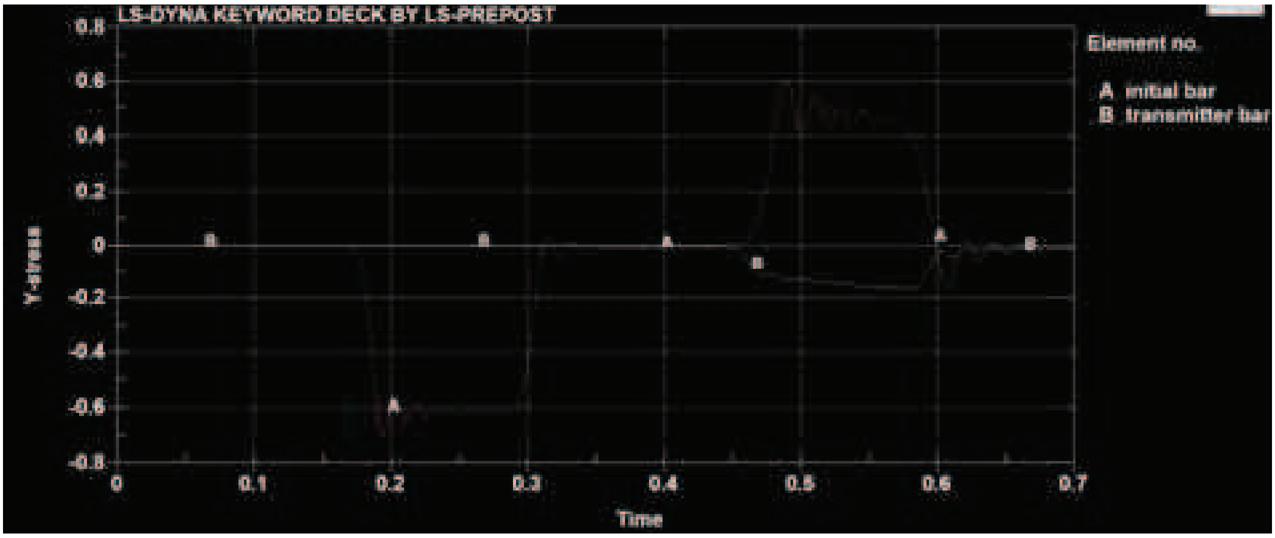

Fig. 17. The incident, reflected and transmitted pulses calculated with LS-DYNA

References

[1] Tasneem, N., *Study of wave shaping techniques of split Hopkinosn pressure bar using finite element analysis*, Wichita State University, 2005.

[2] Jankowiak, T., Rusinek, A., Lodygowski, T., *Validation of the Klepaczko-Malinowski model for friction correction and recommendations on Split Hopkinson Pressure Bar*, Finite Elements in Analysis and Design 47, 1191–1208, 2011.

[3] Kolsky, H., *An investigation of the mechanical properties of materials at very high rates of loading,* Proc. Phys. Soc., 62B, 676, London 1949.

[4] Johnson, G. R., Cook, W.H., *A constitutive model and data for metals subjected to large strains, high strain rates and high temperatures,* in: Proceedings of the Seventh International Symposium on Ballistics, pp. 541–547, 1983.

[5] Ramírez, H., Rubio-Gonzalez, C., *Finite-element simulation of wave propagation and dispersion in Hopkinson bar test,* Materials and Design 27, 36–44, 2006.

[6] Kamal Hossain, M., *Dynamic simulation of split Hopkinson pressure bar(SHPB) for composite materials using LS-Dyna,* University of Nevada, (UNLV) Energy Methods II Course # MEG 795, Las Vegas 2003.

[7] Livermoer Software Technology Corporation (LSTC) *LS-DYNA*, *Keyword user's manual* Vol. 1, 2007.