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SHOCK BEHAVIOR ANALYSIS FOR CERTAIN ALLOY STEELS

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Abstract - During the tests for evaluating shock behavior for certain alloy steels, one of the stages consists of an analysis of geometrical and structural degradations. These degradations are functions of stress distribution, values and module of plastic and elastic deformation energies involved. High values of kinetic energy generated at shock imposed the necessity for a scientific model of study / simulation. The presented model allows a further extension for ranges of values and restrictions imposed to shock stresses for certain alloy steels special structures. In order to evaluate and calibrate the presented model, some experiments were conducted. Data resulted from experiments was compared to data resulted during simulations. After calibration and confirmation of proposed model, new parameters could be computed, parameters that were unavailable in experimental studies. The present paper presents some considerations regarding the adopted methodology, results and perspective for further experimental trials and simulations.

***Keywords* -** impact, alloy steels, model, deformation energy

I. GENERAL DATA AND RESEARCH STAGES

DESIGN analysis stage had the objective of preparing data, hypothesis and general model input, required for simulation of shock behavior for the selected materials. The selected materials were certain alloy steels [1]. By simulation, certain aspects like deformation speed, acceleration of certain points located on the surface of the material or in depth and unitary stresses in certain points can be evaluated.

The objectives for the first stage of the analysis were to analyze the experimental results for shock testing. Experiments aimed at evaluating the geometry of the material after applying the shock, evaluating the presence of metallographic structure alterations, evaluating the micro-hardness in the stresses sections and evaluating the presence of cracks.

One particularity of the presented working method is the values obtained by experiments were the input data for the simulation. By comparing geometrical data obtained in the two situations, by experiments and by simulation, a first evaluation of the simulation model was conducted.

The next objective was to determine by simulation the values of energies generated by the shock input. This allowed to identify the evolution of elastic and plastic deformation energies for one steel plate, of known thickness and subjected to shock input in well defined and known conditions.

This also allowed to study the behavior of the metallographic structure of the material, at certain values of kinetic energy applied, and, the generation and evolution of any cracks or fractures.

By measuring the micro-hardness in a plane that intersects through the point of application of the input load, the study of the deformation rate of the structure and correlation with the metallographic imaging was possible.

In order to achieve the purpose objectives the following steps were conducted:

1) *conduct the experiments on a steel plate, of known composition, subjected to a shock input using a penetrator with an impact kinetic energy of 13.7 (kJ);*
2) *elaboration of a finite element model using and agreed software application;*
3) *validation of the model by comparing simulation results to experimental results;*
4) *measuring the evolution of energies obtained in the simulation;*
5) *results analysis and evaluate the rate of satisfaction for the achieved results;*
6) *identification of certain aspects of the model that need further improvement, in order to increase complexity and get as close as possible to real-life behavior.*

Further use of the model will only be done by particularization to real life use situations.

II. EXPERIMENTAL RESEARCH

For analysis, during the experiments, the alloy steel plates used have the chemical composition presented in table I. Mechanical characteristics of this material are presented in table II.

The thickness of the plate used was of 4 (mm), having the dimensions of 150x150 (mm). The plates were simply supported and acted with a shock input generated by a penetrator having the impact kinetic energy of 13.683 (kJ), at a speed of 700+/-2.0 (m/s). The value of

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the obtained kinetic energy was very close to the imposed value and was obtained using a mass of impact of 17.125 (kg), at a speed of 20 (m/s).

TABLE I
CHEMICAL COMPOSITION OF THE ALLOY STEEL PLATES USED IN THE EXPERIMENTS

Material	Chemical composition (%)							
	C	Si	Mn	Cr	Mo	Ni	P	S
Material 1	0.25 …. 0.31	0.18 …. 0.35	0.30 …. 0.55	1.80 …. 2.3	0.25 …. 0.35	Max. 0.5	0.030	0.030

TABLE II
MECHANICAL CHARACTERISTICS OF THE ALLOY STEEL PLATES USED IN THE EXPERIMENTS

Material	σ_c	σ_r	A	Z	KCU	HB	HRC
	(daN / mm^2)		**(%)**		**(daJ / cm^2)**		
Material 1	**100**	**110**	**15**	**55**	**6 … 12**	**285 … 341**	**28.3 … 35.0**

The specimens were grouped in 5 sets of 3 plates each; all samples belonged to the same cast that passed all reception evaluations. A set was kept as a material sample while all others were subjected to shock inputs. Dimensional analysis together with macroscopic analysis conducted aimed at:

1) *the precise measure of the real deformations of both sides of the metallic plate;*
2) *evaluation of the effective thickness of the plate after being subjected to shock and variation of the thickness with respect to the distance to the application point;*
3) *evaluation of the section profile for the deformed area;*
4) *identify any particularities (if any) regarding the perforation depth and deformation profile.*

All measurements on the profile of the deformation of the plates were conducted on both sides, having a precision of +/- 0.01 (mm). The measuring points were located on a straight line, passing through the impact point and parallel to the middle axis of the plates.

For each set of samples, a graph of mean measured deformations was created, for both measurements on the impact surface and posterior surface. The obtained values represented a fundamental criterion in evaluating the accuracy of the model. Mean values of the effective deformations on the impact surface, for the 4 sets of samples, named P1 ... P4, which was subjected to shock input, are presented in fig. 1.

Mean values of the effective deformations on the posterior surface are presented in fig. 2. Fig. 3 present the mean value of plate thickness, after the shock input was applied.

After analyzing data from fig. 1, 2 and 3, one can notice that the dimension of the influenced area in inversely proportional with the deformation in the point of application of the shock input.

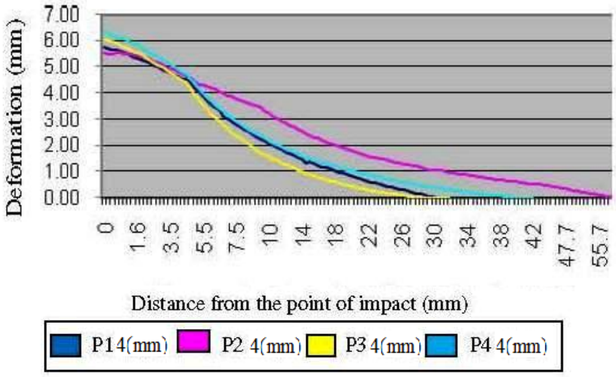

Fig. 1. Mean values of measured deformation on the impact surface

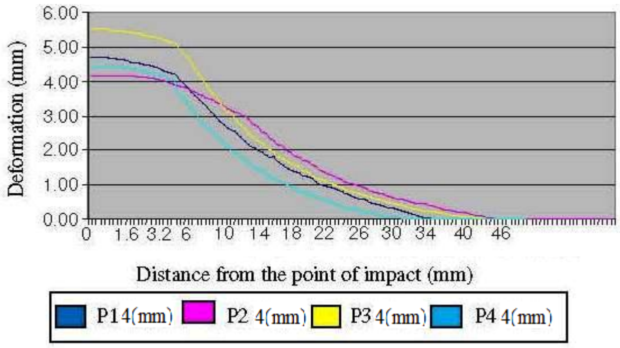

Fig. 2. Mean values of measured deformation on the posterior surface

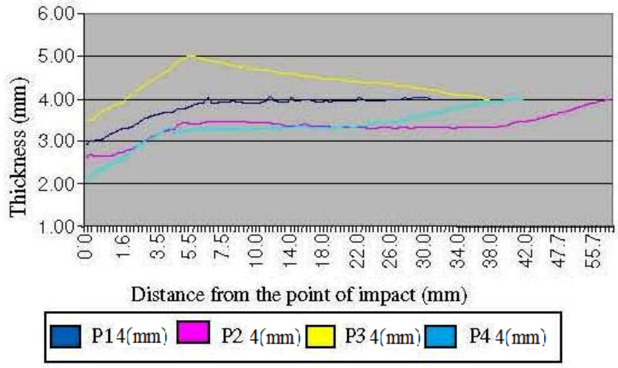

Fig. 3. Mean value of plate thickness

One can also notice that at the point of impact, a cone shape tends to appear, oriented inversely to the solicitation and having the geometrical axis in the direction of the solicitation. the presence of the cone shape is due to the deformation of the penetrator. Its height is not more that 10% of the plate thickness.

By analyzing the curves of effective thickness after impact presented in fig. 3, one can identify the geometry of the deformation zone. For the tested samples, having a thickness of 4 (mm), 3 distinct slopes can be observed, each having a height of approximately 30% of the height of the cone.

Also, one can notice a deformation of the plate and the appearance of a crater shape profile, deformation mostly obtained in the P3 set of samples.

III. MODEL ELABORATION

In order to be able to reproduce the phenomena of shock behavior, LSDYNA3D software solution was used. The application was agreed before by the authors [2].

All conditions to simulate the impact of geometric, material and kinematic used in the experiment were entirely applied.

When modeling the shocking behavior input data, the following were taken into consideration:

1) *determining the remaining deformations of the material, for a sample, measured in the median plane, both of the surface of impact and on the posterior surface;*
2) *determining the kinematic parameters for certain points in the median plane of the sample plate;*
3) *determining the unitary stresses in the material and the variation patterns for these stresses, in certain points of the plate, by taking into consideration the location of the supports and type of supports.*

In order to have a valid analysis of the material behavior, the model must fulfill the following conditions [3], [4], [5]:

1) *represent the exact behavior of the material (fidelity);*
2) *allow stress and displacements / deformations measurements in various sections of the model;*
3) *allow the determination of total value for stresses, axial forces, pressures and rotational moments in certain points or sections;*
4) *require a reasonable amount of time for input data preparation;*
5) *export results in a data format that can be further edited and analyzed using additional software applications.*

The following stages / steps were conducted:

1) *geometry definition, material characteristics, value and application model for the input forces; no equivalences were considered necessary for geometry, material or input forces;*
2) *the material type was selected (viscous-elastic);*
3) *finite element mesh was created, taking into account all notes from literature and the hexahedron was selected as the preferred type of finite element to be used;*
4) *using literature data for similar shock inputs on samples one has established the type of contact between elements: eroding surface to surface solution; this particular type of contact presents the disadvantage of limiting the deformation of the finite element to a value of $2x10^{-5}$ (mm); exceeding this value, the finite element is eliminated from computation; on the other hand, this particular type of contact, presents the advantage of extending the capabilities of the model to shock application in different directions to the normal plane of the surface;*
5) *shock simulations were conducted;*
6) *evaluation of results and comparison to experimental results were conducted.*

After the model was completed, different shock simulation was conducted and results obtained from the simulation were compared to the deformations obtained by experiments. Differences lower than 2% between the two situations allowed a first validation for the model. A second criterion used was the comparison between the acceleration graph of the point of impact obtained in the simulation to those in the literature. These results allowed for a further validation of the model.

The acceleration graph is presented in fig. 4.

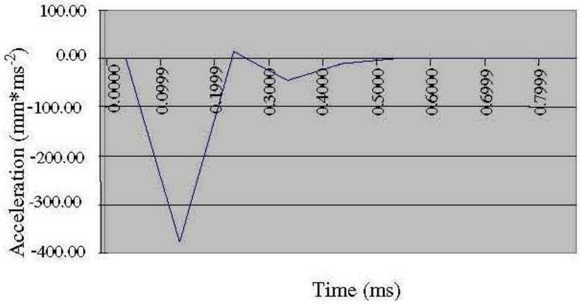

Fig. 4. Acceleration graph at the point of impact

IV. RESULTS

As results of the simulation, one has obtained graphs that present the evolution of plastic deformation energies/stresses in the plate (subjected to shock input), the internal energy of the plate and deformation mechanical work, all with respect to the kinetic energy of the penetrator. Values for these graphs are presented in fig. 5.

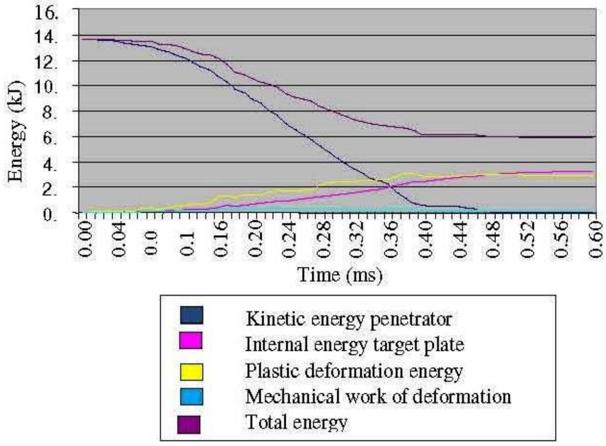

Fig. 5. Energies / Stresses evolution on shock input.

In order to analyze the oscillations of the plate, a graph of accelerations for 2 points belonging to the median line was drawn; points were positioned 36 (mm) and 75 (mm) away from the point of application of the shock input force. The graph presented in fig. 6 was generated.

These results were completed using metallographic analysis, which, at a rate of 800x zoom, did not prove any significant structural alterations in the plate material.

Also, the variation pattern for the microhardness in the deformed area was established. Areas with same values were identified and border map was established.

No signs of cracks or even unopened micro-cracks were found, except one sample, which generated a crack due to a microstructural material failure (a non-metallic inclusion located at a depth of 1.3 (mm) from the surface of impact and 3 (mm) in lateral to the point of impact)

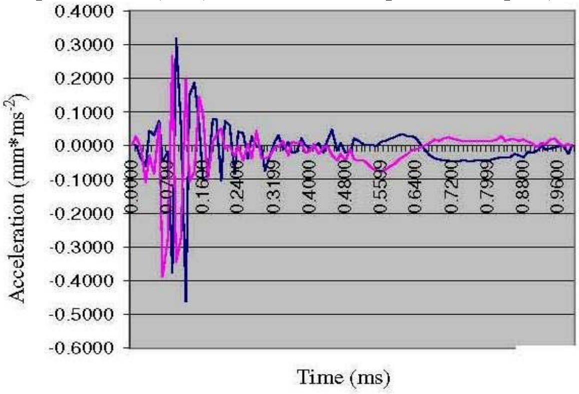

Fig. 6. Time variation for the acceleration of 2 points, belonging to the median line of the impact surface.

V. CONCLUSIONS

By analyzing the energy variation pattern, one has noticed the following:

1) *plastic deformation occurs in a total interval of 0.5 (ms);*
2) *during the first 0.3 (ms) the plate experiences a severe deformation, mostly because of elastic deformations and the appearance of oscillations;*
3) *elastic bending appears along the median planes directions, due to the support system of the plate (simply supported on the four corners, for a square shaped plate);*
4) *by combining elastic with plastic deformations, the result is a variation in the plastic deformation energy in the interval up to 0.4 (ms);*
5) *the plastic deformation energy has the maximum value of 2.99 (kJ); the value is obtained at 0.47 (ms) from the time of impact;*
6) *at this time, the plastic deformation energy has affected a volume of 2.89 (cm^3) of the material.*

By analyzing the metallographic images of the impact area, one has noticed the following:

a) *the material shows typical structures for hypereutectoid alloy steel with chromium, nickel and molybdenum;*
b) *the material presents sorbite and troostite recovery structures;*
c) *both on the impact direction and radial to the impact direction, at different distances from the plate surface, at the selected zooming factor, no significant structural differences in the material structure were noticed.*

By analyzing the micro-hardness (HV 0.1), measured in sections at intervals of 0.1 (mm) between the measuring points, one has noticed the following:

1) *although the circular deformation area has a mean diameter of 40 (mm), the area where micro-hardness was modified has the shape of a truncated cone, having the larger basis on the impact surface and having the diameters of 9 (mm) and 3.5 (mm), respectively;*
2) *measured values allowed identifying the hardening zones and the disposal pattern for them.*

By correlating the data obtained from simulation with the experimental results and metallographic analysis, one can draw the conclusion that the material used has the ability to absorb energies of value equal to the ones given. The overall behavior of the material is good, as the maximum deformations are within the accepted limit range and no cracks have developed.

Last but not least by analyzing the geometry of the deformations, one has noticed that the material does not form any bulges around the point of impact.

The elaborated model allows data extension for the input data so the analysis can broaden. This is a very important aspect, as the model allows a quick modification of the following aspects:

1) *the geometry of the analyzed material;*
2) *material properties / characteristics;*
3) *finite element type;*
4) *mode and parameters of finite element meshing;*
5) *direction and values of input forces applied to the material.*

The particularity of the presented analysis is represented by the fact that the data used in the analysis was used in an experimental application.

After validation, the model allows for evaluation of different parameters, for which, an experimental determination would require high-end precision devices.

The presented model also allows for the study of the oscillating behavior of a plate subjected to shock, study of assembly and fixing solutions for such a plate in a given metallic assembly and study of parts and pieces created from alloy steels with high resistance structures.

By analyzing the general problem of metallic materials cracking phenomenon, in particular for the case of homogeneous plates of carbon steels or lightly alloyed steels, the results obtained by theoretical analysis using finite element modeling and experimental research, reveal analysis directions and possibilities, restrictions and particularities for interpretation of the phenomena that develop in the particular case of shock.

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