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# INVESTIGATION OF THE EFFECT OF PLATE DIMENSIONS AND THICKNESSES ON THE IMPACT EFFECT OF A STEEL BALL

**M. Murat Yavuz[1]**

[1]Osmaniye Korkut Ata Univ. Faculty of Engineering, Energy Systems Eng. Department, Turkey
muratyavuz@osmaniye.edu.tr

## ABSTRACT

In this study, impact effect of a ball is investigated on different dimensions of plate geometries by using computational impact analysis. All modelling and solution steps are done by ANSYS LS-DYNA package software. A plate is fixed from its side locations and a steel ball is thrown towards plate. Standard steel properties are used in material properties determination. Kinematic hardening plasticity model is selected for investigating the plasticity behaviour of ball and plates. Increasing the speed and decreasing the thickness of the ball cause to increase stresses. The highest elastic strains occur in the results of the biggest ball diameter test. Less stresses and more stable results are taken with increasing the thickness of plate. Plastic deformations occur only in the impact tests of the highest ball diameter and the lowest thickness of plate results.

**Keywords**: LS-DYNA, impact, plastic response, ball indention

## 1. INTRODUCTION

Static analyse assumptions and investigations are mostly used for analysing machine elements. However on the contrary to static analyses, most of the machine elements are worked in dynamic conditions. Different types of loadings are shouldered in working time; like bending, torsion, fatigue and etc... Complex and non-effective conditions are usually neglected for simplifying the analyses. However, in some cases machine parts are loaded with time depended and sudden loadings. They show different responses in instantaneous and time depended loadings, compared to static conditions. Also, the continuity of unique part can be collapsed. Hence, different approaches are needed to investigate dynamic and impact conditions of parts.

The usage area of dynamic analysis is very wide, but mostly used in the investigation area of forming processes, blast and impact analyses in the literature. Different researchers used for dynamic investigations in different areas like hydroforming of tubes [2,11,14,15], sheet metal forming [4,8,13] and so on. One of the essential application areas is the measuring of impact behaviour of composite materials and researches are mainly focused on this subject. Some findings can be summarized as; combination of different materials or geometrical orientations [2] behaves better than one material or geometrical orientation in the impact analyses of composites. A wide range of application area of composite materials is available in commercial usage and their failure behaviour is also critical. Reinforced concrete can be classified as one of the composite types. When the failure of reinforced concrete is investigated, it is determined that the impact velocity [10] is the main factor of failure. Moreover, using fiber reinforced concrete [5] resists to impact of vehicles more than traditional concrete and they have less fragmented.

Analyses of impact of spheres and other impactor shapes are directly investigated. Minamoto and Kawamura [3] mention that compression of spheres increases linearly with respect to impact velocity. Similar linear behaviour [6] is observed on the number of fragments, local deformations and mass dissipations of a beam by increasing impact velocity. General plastic deformation [12] increases with respect to increasing of impact velocity, if plastic region occurs. The impactor geometry [7], especially the tip shape of impactor affects the impact response and failure mode. Also impactor position is important [1], especially in the results of cracking of non-symmetrical geometries like eggshells. Other analyse parameters [9] also influence the results; especially element size, number of shell element layers, contact penalty stiffness.

In the literature, numerical analyses give sufficient results in the most of the cases and behave similar characteristics when they are compared with experimental studies. Impact and failure is mostly seen in

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machine parts and their covers. Different plate geometries and thicknesses are investigated to gain more knowledge on the impact effect and plastic response in this study. Hence, it will provide more information for further design and development conditions.

## 2.MATERIAL AND METHOD

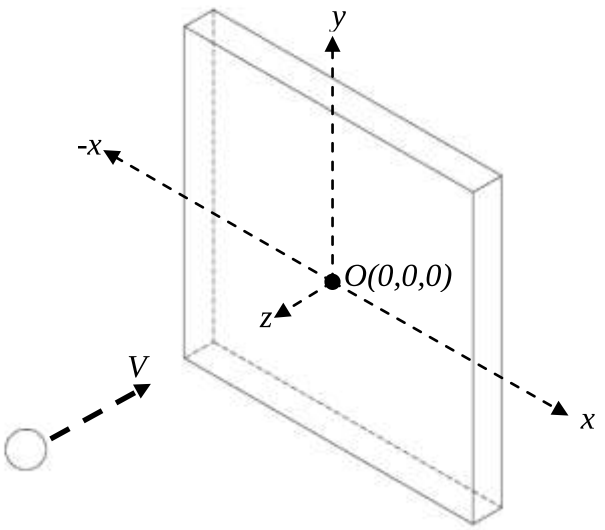


*Figure 1. Ball and plate geometries*

Computational dynamic analysis is used in this study. This analyse technique gives some benefits like no experimental setup requirements. Developments on the computer science and numerical analyse techniques provide to increase the popularity and give less error on computational analyses. Package software, ANSYS LS-DYNA is used for modelling, applying initial and boundary conditions, solving and illustrating the results. Analysed ball and plate model is demonstrated in Figure 1. The results are taken on the surface of plate from x-directions, which are used from Figure 5 to Figure 8. The elastic strain results are taken from *0* (0,0,0) location with respect to time and they are given for different cases in Figure from 9 to 13.

Typical AISI 1018 steel material properties are used in the analyses and its properties are given in the table 1. Two types of plasticity behaviour are available in hardening region; isotropic and kinematic hardening. Hardening parameter is used for determination of plasticity property of the material. If hardening parameter (β) is set zero, only kinematic model is used. Else if it is set up to one, isotropic hardening model is used. If the hardening parameter (β) is between zero and one, a combination of isotropic and kinematic hardening models is used. Kinematic hardening is used by setting hardening parameter (β) as zero in this study. Also Bauschinger effect is included by using Kinematic hardening plasticity. The yield surface of material does not expand with respect to the increase of yield stress. Hence hardening parameter (β) is selected as zero.

*Table 1. The used 1018 typical steel properties in the analyses*

| | |
|---|---|
| Density, ρ | 7865 kg/m$^3$ |
| Young modulus, E | 200 GPa |
| Poisson's ratio, υ | 0.27 |
| Yield stress, $\sigma_y$ | 310 MPa |
| Tangent modulus, $E_{tan}$ | 763 MPa |
| Hardening parameter, β | 0 |
| Strain rate parameter, C(Cs) | 40 |
| Strain rate parameter, P | 5 |
| Failure strain, $\varepsilon_p$ | 0.75 |

The plastic kinematic hardening model is depended on strain rate dependency and failure of material. Strain rate of material model is harmonized with Cowper-Symonds model [17] which scales yield stress of material by strain rate dependent factor, can be seen in the Eq.1. C and P are strain rate parameters, used in the equation 1.

$$\sigma_y = \left[1 + \left(\frac{\dot{\varepsilon}}{c}\right)^{\frac{1}{P}}\right] \times \left(\sigma_0 + \beta E_p \varepsilon_P^{eff}\right) \quad (1)$$

Where $\sigma_0$ is the initial yield stress, $\acute{\varepsilon}$ is the strain rate, C and P are strain rate parameters, $\varepsilon_p^{eff}$ is effective plastic strain and $E_p$ is plastic hardening modulus. $E_p$ is given in the Eq.2.

$$E_P = \frac{E_{\tan} E}{E - E_{\tan}} \quad (2)$$

In all analyses, the distance between ball and plate is taken constant; 0.2 m. Hence interaction time and behaviour between ball and plate can be different with respect to applied initial velocity. Geometrical properties and applied initial velocities are given in the table 2. All dimensions are given in SI units.

*Table 2. Properties of the models and analyses*

| Test number | Ball diameter (m) | Thickness of plate (m) | Side length of plate (m) | Velocity of the ball (m/s) |
|---|---|---|---|---|
| test-1 | 0.02 | 0.02 | 0.02 | 5 |
| test-2 | 0.02 | 0.02 | 0.02 | 25 |
| test-3 | 0.02 | 0.02 | 0.02 | 125 |

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| | | | | |
|---|---|---|---|---|
| test-4 | 0.02 | 0.01 | 0.02 | 125 |
| test-5 | 0.02 | 0.04 | 0.02 | 125 |
| test-6 | 0.01 | 0.02 | 0.02 | 125 |
| test-7 | 0.04 | 0.02 | 0.02 | 125 |
| test-8 | 0.02 | 0.02 | 0.01 | 125 |
| test-9 | 0.02 | 0.02 | 0.04 | 125 |

## 3. FINITE ELEMENT MODELLING

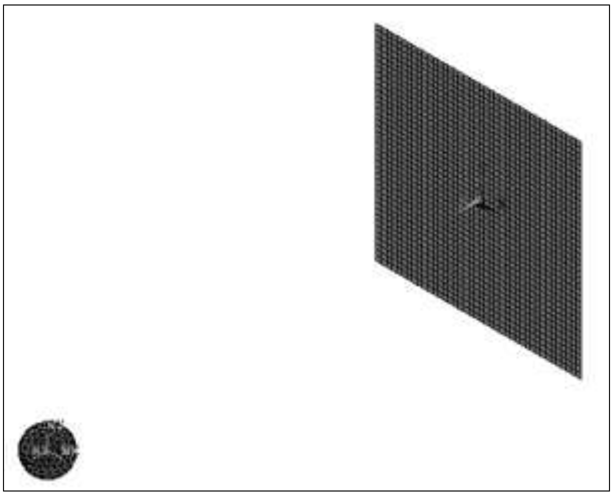

*Figure 2. Finite element model of ball and plate*

Finite element models of sphere and plate are modelled in ANSYS pre-processor step. SOLID 164 elements are used in the sphere modelling. This element is used for 3D modelling of solid structures and its nodes have degree of freedoms on translations, velocities and accelerations in x, y and z directions. On the contrary to use solid elements in modelling of plate, SHELL 163 elements are used in plate modelling. This element has four nodes and all its nodes have degrees of freedom on translations, accelerations and velocities in x, y and z directions with rotations around x, y and z axes. Belytschko-Tsay element formulation is selected in shell elements which is the default formulation model of plates in ANSYS. The finite element models of sphere and plate are given in Figure 2. Plate is modelled in shell elements, which cannot illustrate the thickness. But thickness property of plate is included by ANSYS LS-DYNA in the solution of analyses.

### 3.1. Initial and Boundary Conditions

The initial condition is applied only on sphere. Initial velocity is added to sphere and the sphere is directly moved to the plate with constant speed. Boundary conditions are also applied only on the plate by fixing the plate from its sides.

### 3.2. Contact Definitions

Contact definition is one of the requirements of impact analysis. The behaviour of interaction of two separated parts is affected with respect to contact properties. In 3D analyses, different contact models are available in the ANSYS LS-DYNA. 3D surface to surface general contact model is defined in this study and the effect of friction is neglected by setting friction coefficient as zero.

## 4. RESULTS

The number of elements can affect results of the solution in FEA. Finite element model of ball and plate is investigated for the effect of number of used elements. Hence mesh convergence analysis is initially applied. Number of elements of the constructed models is increased and the change of one of the important result is checked. The ball is thrown with a velocity and a gravitational acceleration. The change of Von Mises stresses in the plate is observed with respect to increased number of elements in the analyses. Mesh convergence is achieved when the number of elements is approximately equal or greater than 3.000. It is given in Figure 3.

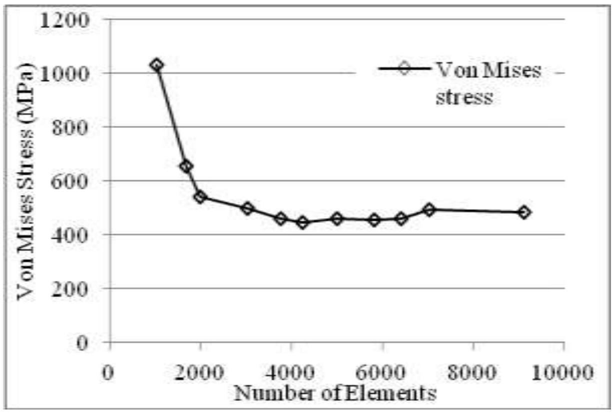


*Figure 3. Maximum Von Mises Stresses in the plate with respect to the number of elements*

An impact illustration of ball and plate is given in Figure 4 for test no-2. The ball begins to move with respect to time and interacts approximately when the time approximately equals to 0.009 second. Then the ball recoils from the plate to backward direction. The colour changes demonstrate the Von-Mises stress formation. Only one parameter is changed from Figure 5 to Figure 9 and its effect is investigated. The results of impact analyses are given for an instant time, which equals to 0.09 second.

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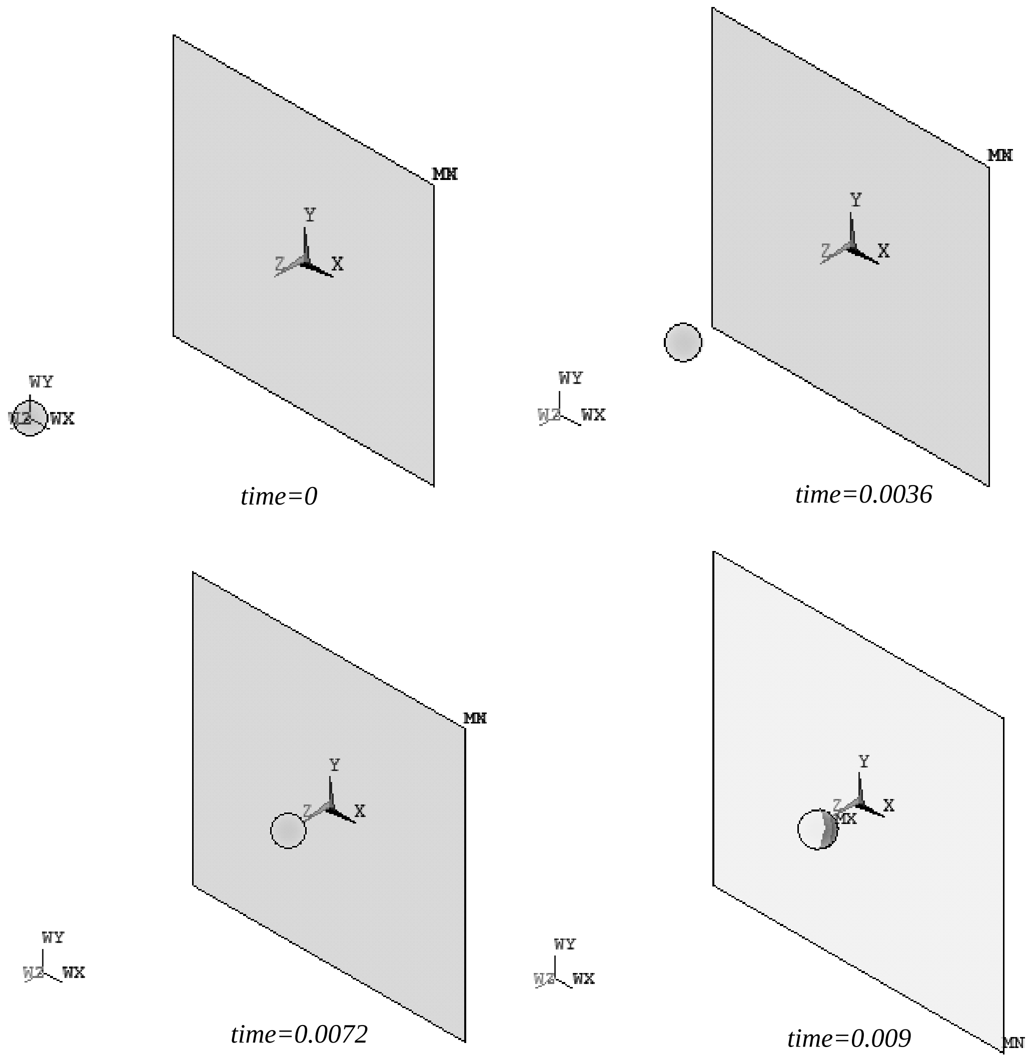
The ball is thrown to the plate with three different velocities. In this manner, the velocity effect is investigated and it is given in Figure 5. The results are taken from along the x-direction location and it can be seen in Figure 1. It is expected and determined that the highest velocity test has the highest stresses in the three impact test comparisons. When decreasing velocity of the ball, stress levels are decreasing. In the each impact test in Figure 5, high stresses occur at the side locations of plate. Side locations have similar characteristics and they have the highest stresses. However, the lowest stresses occur at the centre of the plate in test no-3; rather than test no-2. The lowest stresses occur near the side locations; approximately between ±0.06 and 0.07 locations in the results of test no-2. No yielding occurs in these impact tests. Increasing the impact speed gives higher stresses.



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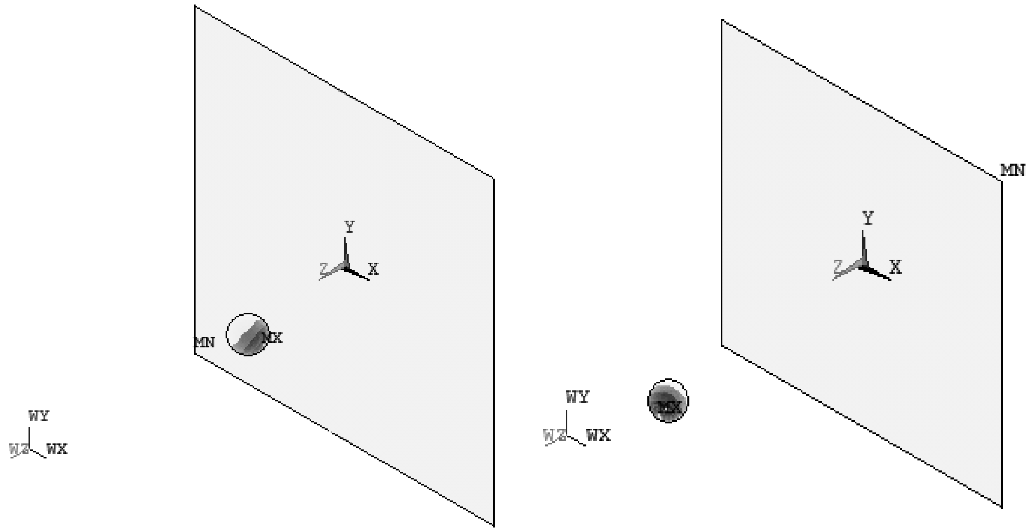


*Figure 4. Impact of ball with respect to time for test no-2*

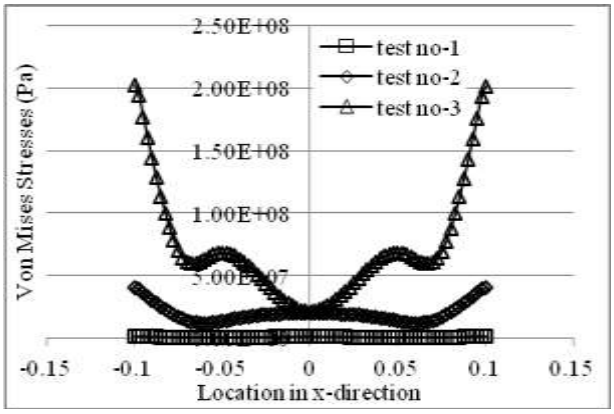


*Figure 5. The effect of impact speed on the formation of Von-Mises Stresses in the plate*

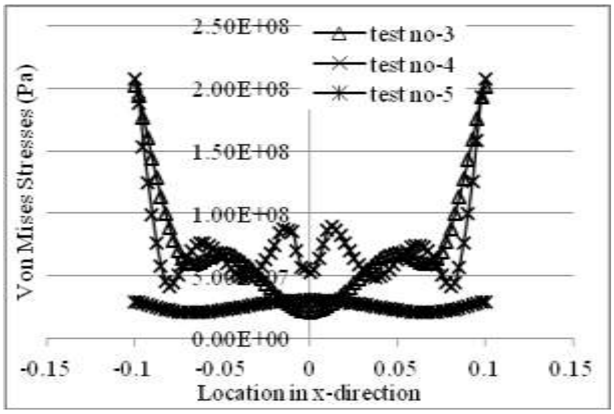


*Figure 6. The effect of thickness of plate on the formation of Von-Mises Stresses in the plate*

The effect of thickness of plate on the impact response is analysed and its results are compared in Figure 6. Test no-4 has the highest stresses and they are formed at the sides of the plate. A small oscillation in the stress distribution is observed in test no-3 and test no-4. The lowest stresses occur at the centre of the plate in test no-3 which has medium thickness. The stress distribution changes and the lowest stresses occur near sides of the plate in test no-3 when increasing the thickness. Further increments of the thickness provide a more stable and low stress distribution.

The mass of ball is also critical and directly affects the impact condition. Increasing the ball diameter causes to increase the mass. The mass is increased or decreased with respect to changing the ball diameter. The effect of diameter of ball is investigated and its results are given in Figure 7. Test no-6 has the lowest ball diameter and its results have more stable and the lowest stress distribution. Test no-7 has the highest ball diameter and it is expected that its results have the highest stresses. However it has lower stresses than test no-3 results. But test no-7 results has a more oscillating stress distribution than other results and it's the highest stress occurs near location of the centre of plate. The oscillation may be caused from the plastic flow of the plate. Test no-3 has the highest stresses and they occur at the side locations of the plate.

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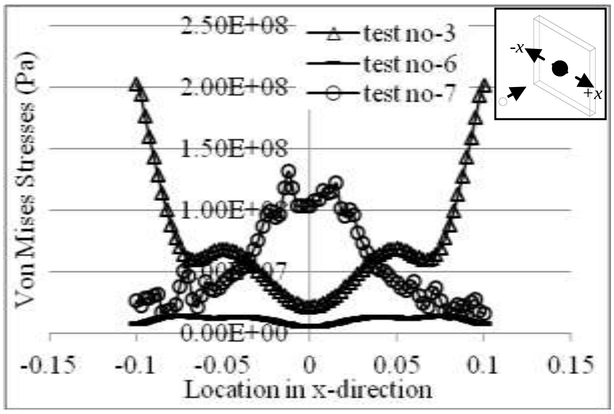


*Figure 7. The effect of diameter of the ball on the formation of Von-Mises Stresses in the plate*

In Figure 8, the length and height of plate dimensions are chanced and its effect is investigated. Same change ratio is applied on both sides of the plate. When increasing the sides of plate, the stress distribution is changed, but symmetry of stress results on the centre of the plate is protected. The highest stresses occur in test no-3. When increasing or decreasing sides of the plate, stress distribution decreases.

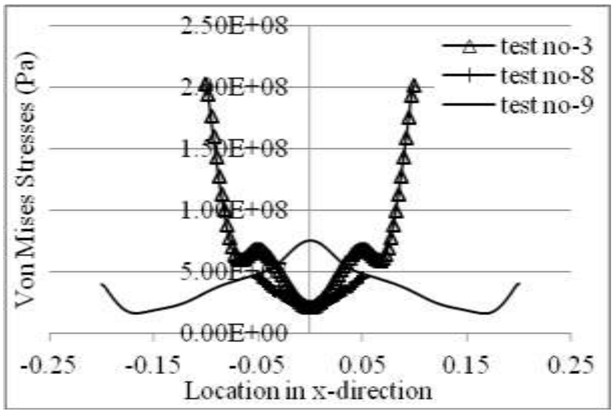


*Figure 8. The effect of side lengths of plate on the formation of Von-Mises Stresses in the plate*

The results of impact speed effect on the Von Mises elastic strain are given in Figures from 9 to 12 for only origin node (coordinates; 0,0,0). The range of stress results are given for a time length of 0.09 second. The strain formation on the plate begins with different times with respect to initial ball velocity. When ball has a velocity of 125 m/s, the interaction of plate and ball occurs more rapidly than lower velocities.

High velocity cause high elastic strains and range of the strains are greater than lower velocity results in Figure 9. Distributions of elastic strains have not similar behaviour. This may be caused from the impact time and impact energy. The effect of thickness of plate on the elastic strain is given in Figure 10. The highest stress peak points are nearly same between test no-3 and test no-4. The elastic strains and ranges increases with respect to decreasing the thickness of plate. Also the frequency of elastic strain is increasing with decreasing the plate thickness. More stable strain distribution is gained by increasing the thickness of the plate.

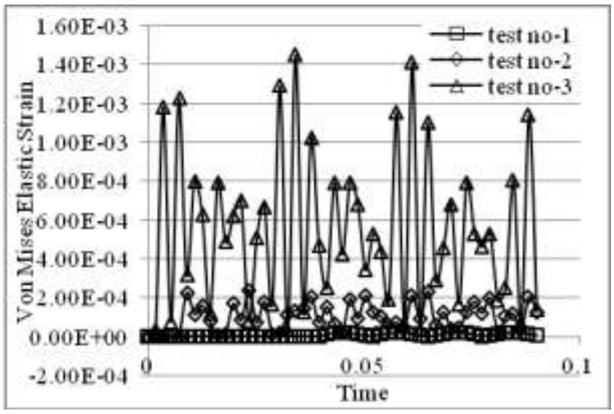


*Figure 9. The effect of impact speed on the formation of Von-Mises Elastic Strain in the plate*

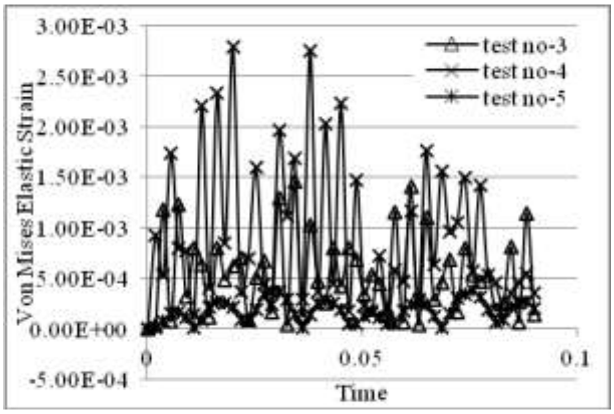


*Figure 10. The effect of thickness of plate on the formation of Von-Mises Elastic Strain in the plate*

Elastic strain distributions are given in Figure 11 for impact tests of different diameters of balls. Test no-7 has the highest ball diameter and gives highest elastic strains, but frequencies of elastic strains are less. Decreasing the diameter of ball gives less elastic strains.

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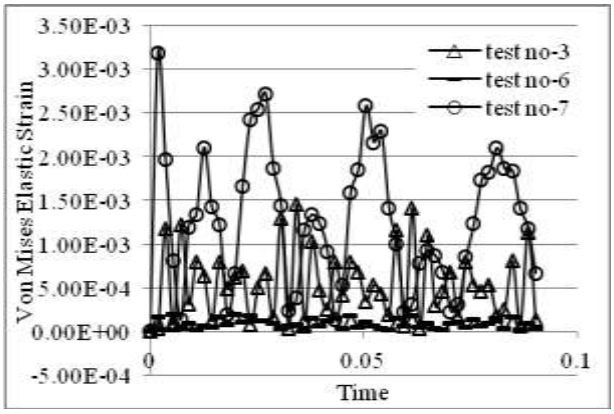


*Figure 11. The effect of diameter of the ball on the formation of Von-Mises Elastic Strain in the plate*

The effect of dimension of plate is given in Figure 12. The range of elastic strains is different and has the highest level in the medium side lengths of plate results (test no-3). Not only has less, but also high side length dimensions of the plate given less elastic strains.

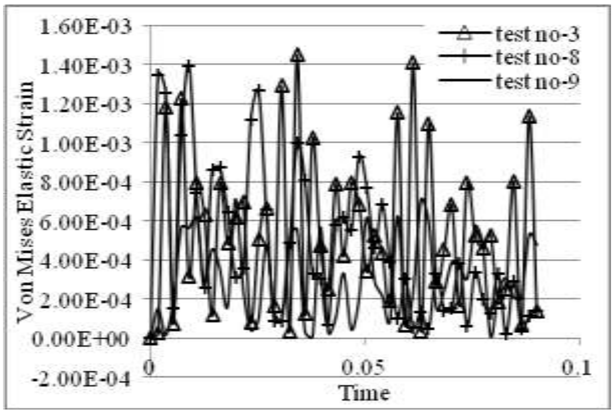


*Figure 12. The effect of side lengths of plate on the formation of Von-Mises Elastic Strain in the plate*

In the whole elastic strain results, the results are chancing with time and give a response of oscillation. On the contrary to elasto-plastic static analyses, this oscillation or dynamic relaxation influence the deformation and stress formations on the plate, which may be prevent or decrease the formation of yielding and plastic deformations.

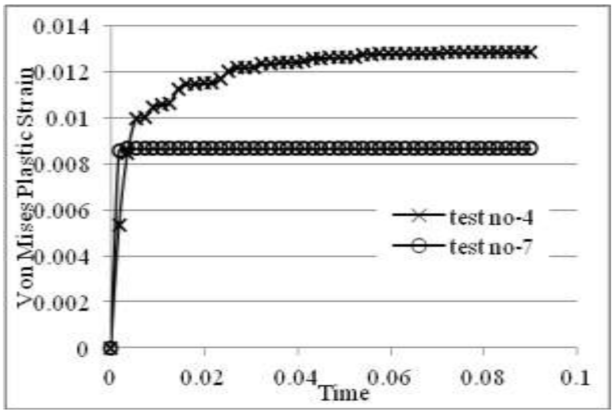


*Figure 13. The formed Von-Mises Plastic Strain in the plate*

The Von Mises plastic strain is given in Figure 13 for test no-4 and test no-7. In other tests, no plastic strains are observed. This is caused from dynamic relaxation and time dependent response of plate. Plastic deformation occurs rapidly and then follows a constant rate with respect to time. Recoiling of the ball from the plate causes this phenomenon. Only an amount of plastic deformations occur in the time of interaction of plate and ball.

## 5. CONCLUSION

Impact response of a ball and a plate is investigated by using computational dynamic analysis. Different plate dimensions and thicknesses are studied. Also dimension and speed of the ball is changed and their effects are compared. Plastic deformation of the plate is observed and the factors are examined.
The main diagnoses are observed in the analyses;

- Mesh convergence is achieved when the number of elements equal or greater than 3.000.
- The stresses are getting higher as a result of increasing the impact velocity.
- The highest elastic strains occur at the highest impact velocity results.
- Increasing the thickness of plate gives more stable and less stress results. Decreasing the thickness of plate can cause to form plastic deformations and also the range, frequency and value of elastic strains are changing and increasing.
- Increasing the diameter of ball causes to increase the stress results on the plate. The increment of the ball diameter cause to form plastic deformations on the plate.
- When the plastic flow occurs, stress distribution of the plate changes.
- Impact results of highest diameter of ball results have highest elastic strains, but have fewer frequencies than smaller diameter of ball results.

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- Increasing or decreasing the surface area of plate changes stresses and gives less stress values with respect to the analyses.
- Plastic deformations occur only in the lowest thickness and highest ball diameter impact results in the whole tests.

The applied analyses provide some knowledge about stress and strain formation and plasticity behaviour of the plates.

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