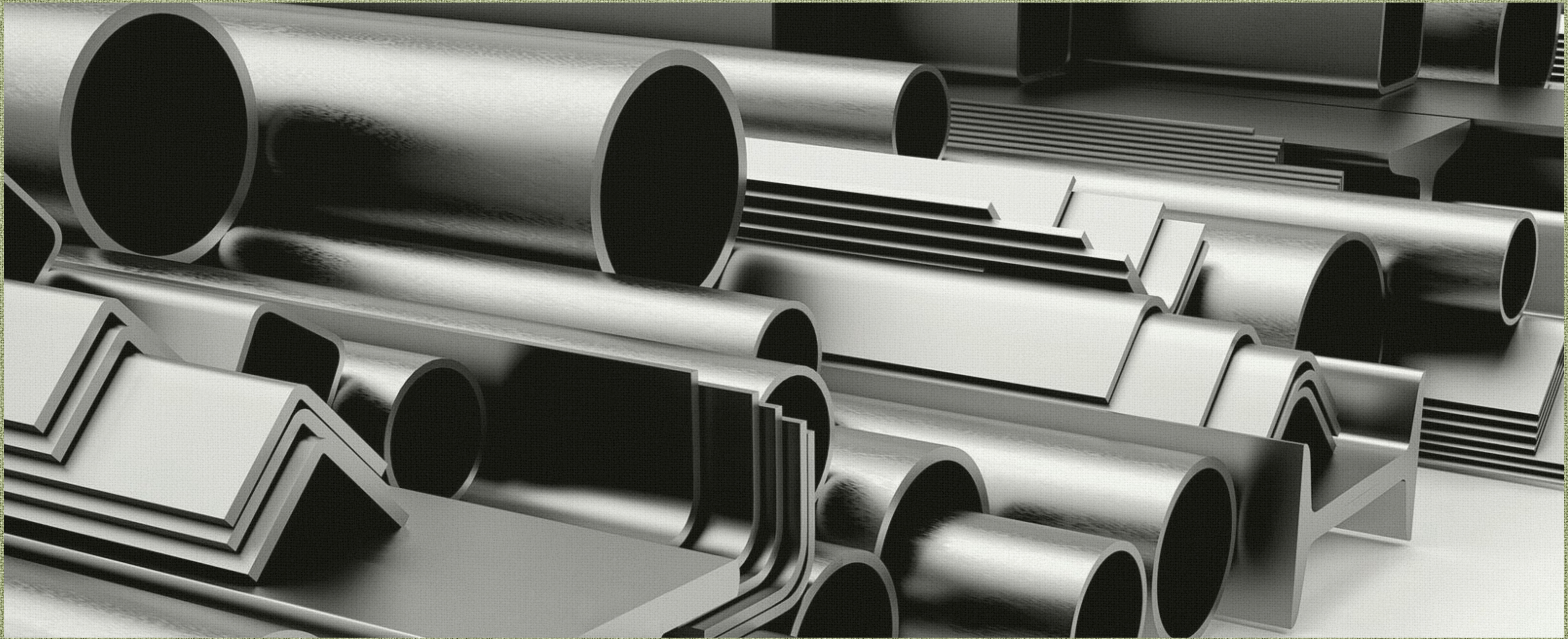

Evaluation of formability of Mg alloys using FEM

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Formability

In materials engineering, formability refers to the **ability** of a material to be shaped or formed into a **desired shape without fracturing or cracking**. Formability is an important property for many manufacturing processes, including **forging, stamping, bending**, and **deep drawing**.

Formability is influenced by several **factors**, including the material's **composition**, **microstructure**, and mechanical properties such as **ductility**, **toughness**, and **strength**. Generally, materials that are more ductile and malleable are easier to form, while materials that are brittle or have low ductility are more difficult to form.

Formability testing is often conducted to quantify a material's formability, such as the **Erichsen cupping test**, the **Nakazima test**, or the **Marciniak test**. These tests involve applying a specific amount of force or strain to the material to determine its ability to undergo plastic deformation without cracking or breaking.

Finite Element Method (FEM)

Finite Element Method (FEM) is a powerful computational tool used to **analyse** and **predict** the **behaviour of materials** and **structures** under various loading conditions. FEM is used to solve problems related to **structural mechanics**, **heat transfer**, **fluid mechanics**, and other fields of materials engineering.

In FEM, the material or structure is divided into small, interconnected elements. Each element is defined by a set of equations that relate its behaviour to the behaviour of adjacent elements. These equations are then combined to form a larger system of equations that describes the behaviour of the entire system.

FEM is particularly useful in materials engineering because it allows engineers to model the behaviour of complex materials and structures that cannot be easily analysed using traditional analytical methods. **For example, FEM can be used to predict the stress distribution in a component during the manufacturing process or to analyse the deformation of a material during a mechanical test**.

FEM can also be used to **optimise the design of materials** and structures by simulating different loading conditions and assessing the performance of various design configurations. This allows engineers to identify potential weaknesses or areas of improvement in a design before it is physically built and tested

Overall, FEM is an essential tool in materials engineering for analysing the behaviour of materials and structures and for optimising their design and performance.

Magnesium and It's Alloys

Atomic Number : 12

Atomic Mass : 24.305 amu

Properties of Magnesium and it's alloys

1. **Low density:** Magnesium is the **lightest** of all the commonly used **structural metals**, with a density of about **1.74 g/cm³**. This makes magnesium alloys ideal for **weight-sensitive** applications where **high strength** is also required.
2. **High strength-to-weight ratio:** Magnesium alloys have a high strength-to-weight ratio, making them ideal for applications where **weight reduction** is critical, such as in **aerospace** and **automotive** industries.
3. **Good machinability:** Magnesium alloys have good machinability, which makes them easy to machine and form into complex shapes.
4. **Good damping capacity:** Magnesium alloys have good damping capacity, which means they can **absorb vibrations** and **reduce noise**, making them useful in applications such as **machinery** and **transportation**.
5. **Corrosion resistance:** Magnesium and its alloys have good corrosion resistance in many environments. However, they can be **susceptible** to corrosion in the **presence of moisture**, which can limit their use in some applications.
6. **Good thermal conductivity:** Magnesium alloys have good thermal conductivity, making them useful in applications such as **heat sinks**.
7. **Good electromagnetic shielding**: Magnesium alloys have good electromagnetic shielding properties, making them useful in **electronic** applications.

Overall, the properties of magnesium and its alloys make them suitable for a wide range of applications in industries such as **aerospace**, **automotive**, **electronics**, and **medical devices**.

Some Most useful alloys of Magnesium

1. **AZ31B:** This alloy contains **3% aluminium** and **1% zinc**, and is one of the most commonly used magnesium alloys. It has good corrosion resistance, high strength-to-weight ratio, and good ductility.
2. **AZ91D:** This alloy contains **9% aluminium** and **1% zinc**, and has higher strength than AZ31B while still maintaining good ductility and corrosion resistance.
3. **WE43:** This alloy contains **4% yttrium**, **3% neodymium**, and **0.5% zirconium**, and has excellent high-temperature strength and good corrosion resistance.
4. **ZK60A:** This alloy contains **5.5% zinc** and **0.45% zirconium**, and has high strength and good toughness, making it useful in aerospace and military applications.
5. **AM60B:** This alloy contains **6% aluminium** and **0.15% manganese**, and has good castability and good corrosion resistance.

These alloys of magnesium are used in a variety of applications, including aerospace, automotive, consumer electronics, medical devices, and sporting goods.

Places where Magnesium alloys are used

1. **Automotive industry:** Magnesium alloys are used in the production of automotive parts such as **engine blocks**, **transmission cases**, **steering wheels**, and **brake pedals**. The use of magnesium alloys in the automotive industry can lead to significant **weight reduction** and **improved fuel efficiency**.
2. **Aerospace industry:** Magnesium alloys are used in the aerospace industry for applications such as **aircraft seat frames**, **helicopter rotor housings**, and **missile** and **rocket components**.
3. **Electronics industry:** Magnesium alloys are used in the electronics industry for the production of **lightweight casings for laptops**, **tablets**, and **mobile phones**.
4. **Medical implants:** Magnesium alloys are used in the production of medical implants due to their **biocompatibility** and ability to be absorbed by the body over time.

Challenges associated with the use of Magnesium Alloys

1. **Corrosion resistance:** Magnesium alloys are highly susceptible to corrosion, which can limit their use in certain applications. Improving the corrosion resistance of magnesium alloys is an important area of research.
2. **Formability:** As mentioned earlier, the formability of magnesium alloys is an important consideration in the design and manufacture of components made from these materials. Improvements in the formability of magnesium alloys could lead to expanded use in applications such as sheet metal forming.
3. **Cost:** The cost of magnesium alloys can be higher than other materials such as aluminium and steel, which can limit their use in certain applications. Reducing the cost of magnesium alloys could lead to expanded use in a wider range of applications.
4. **Flammability:** Magnesium alloys are highly flammable, which can be a safety concern in certain applications. Developing alloys with improved fire resistance is an important area of research.

Why Formability of Magnesium alloys is difficult ?

The formability of magnesium alloys is difficult due to several reasons:

1. **Low formability**: Magnesium has a **hexagonal close-packed (HCP) crystal structure** that makes it **difficult** to deform plastically at room temperature. This low formability can result in **cracking** and **tearing** during the forming process.
2. **High elastic modulus**: Magnesium alloys have a **high elastic modulus**, which means they have a **low ductility** and are more likely to **crack** or **fracture** during deformation.
3. **Poor plastic deformation behaviour:** Magnesium alloys have poor plastic deformation behaviour due to their **limited number** of **active slip systems**, which limits their ability to undergo plastic deformation.
4. **High anisotropy:** The anisotropic nature of magnesium alloys means that they have different properties in different directions, which can make it difficult to predict and control the deformation behaviour during forming.
5. **Susceptibility to deformation-induced cracking:** Magnesium alloys are susceptible to deformation-induced cracking due to their **low ductility** and **sensitivity to localised deformation.**
6. **Surface defects:** Surface defects such as **pores**, **cracks**, and **inclusions** can act as **stress concentrations** and cause **premature failure** during forming.
7. **Limited formability at high temperatures:** While magnesium alloys exhibit better formability at elevated temperatures, they have a **limited operating temperature range** due to their susceptibility to **oxidation** and **other high-temperature degradation mechanisms**.

How can we improve the Formability of Magnesium alloys ?

There are several methods to improve the formability of magnesium alloys:

1. **Hot forming:** Hot forming at elevated temperatures can improve the formability of magnesium alloys by **reducing the material's yield strength** and **increasing its ductility**.
2. **Alloying:** The addition of alloying elements such as **aluminium**, **zinc**, or **rare earth metals** can improve the formability of magnesium alloys by **enhancing** their **deformation mechanisms** and **increasing** their **ductility**.
3. **Grain refinement:** Grain refinement through techniques such as **severe plastic deformation** or **equal-channel angular pressing** can improve the formability of magnesium alloys by **reducing** their **grain size** and **increasing** their **strength**.
4. **Surface treatments:** Surface treatments such as **shot peening** or **laser shock peening** can induce **compressive residual stresses** on the surface of magnesium alloys, which can **improve** their **resistance to cracking** during deformation.
5. **Lubrication:** The use of lubricants during forming can **reduce friction** and **improve** the **flow** of magnesium alloys, thereby enhancing their formability.
6. **Deformation mode control:** By controlling the deformation mode, for example, by using **tension-compression** or **asymmetric rolling**, it is possible to improve the formability of magnesium alloys by **inducing a favourable texture** or **microstructure**.
7. **Modelling and simulation:** Advanced modelling and simulation techniques can aid in **predicting** and **optimising** the deformation behaviour of magnesium alloys, leading to improved formability.

Overall, a combination of these methods can be used to improve the formability of magnesium alloys and enable their wider use in various applications.

How can we evaluate the formability of Magnesium Alloys using FEM ?

Finite element method (FEM) simulations can be used to evaluate the formability of magnesium alloys by analysing their deformation behaviour during different forming processes. The following are some of the general steps which need to be followed:

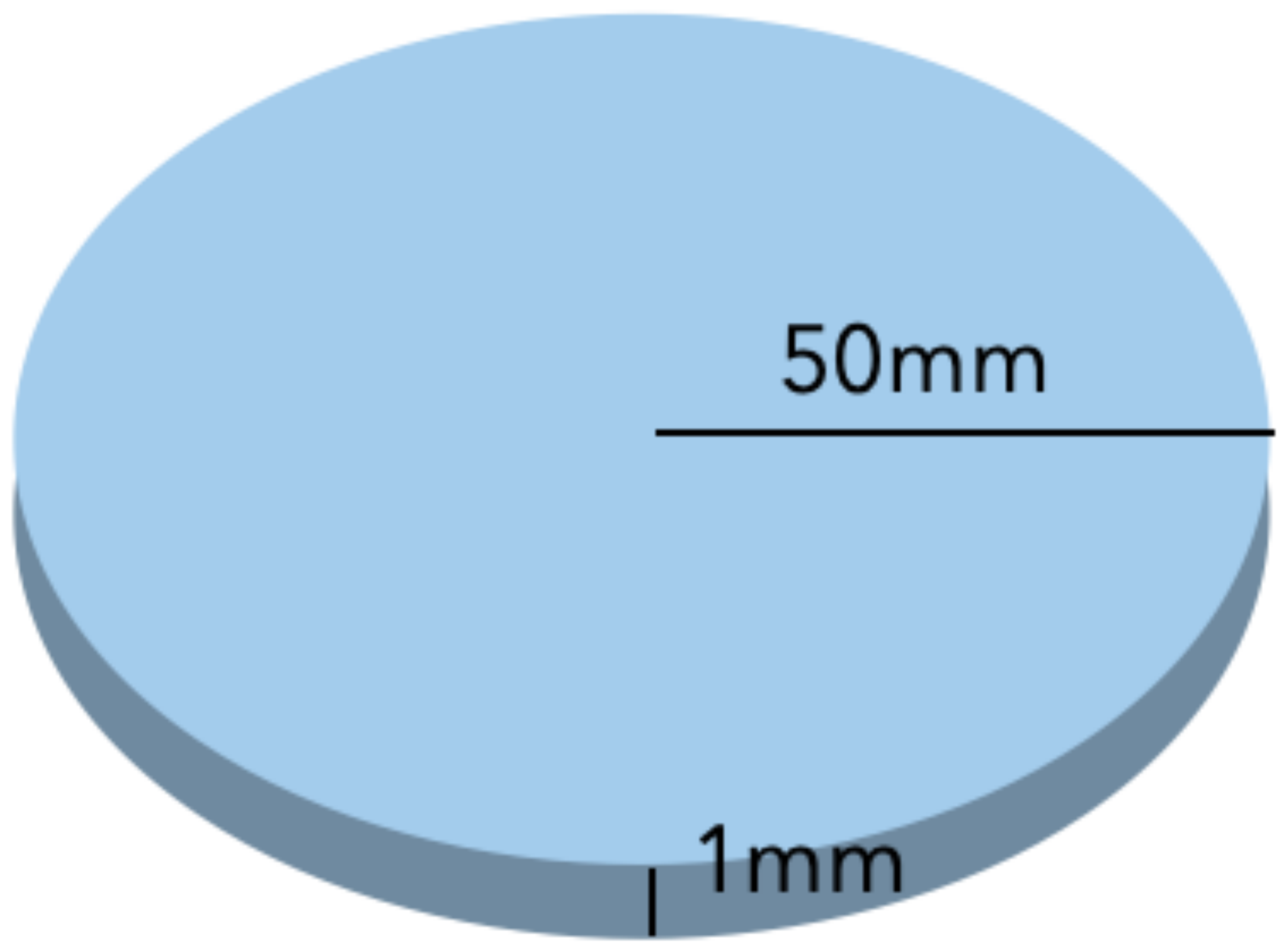
1. **Build a finite element model of the forming process:** The first step is to build a finite element model of the forming process, such as **extrusion**, **forging**, or **rolling**. This model should include the **geometry** of the workpiece, the **tooling**, and the **boundary conditions**.
2. **Define the material properties**: The next step is to define the material properties of the magnesium alloy being formed. This includes the mechanical properties, such as **yield strength** and **elastic modulus**, as well as the **flow stress** behaviour and any anisotropy effects.
3. **Apply the loading conditions:** The loading conditions, such as the **applied forces** or **strains**, should be applied to the model based on the specific forming process being simulated.
4. **Simulate the deformation behaviour:** The FEM software can then simulate the deformation behaviour of the magnesium alloy during the forming process, including the **development of any defects** or **failure modes**.
5. **Analyse the results:** The simulation results can be analysed to evaluate the formability of the magnesium alloy, including its **deformation behaviour**, the **occurrence of defects**, and the **final shape** and **dimensions** of the workpiece.
6. **Optimise the process parameters:** Based on the simulation results, the process parameters can be optimised to improve the formability of the magnesium alloy, such as **adjusting the tooling design**, the **loading conditions**, or the **material properties**.

Overall, FEM simulations can be a valuable tool for evaluating and optimising the formability of magnesium alloys, helping to improve their performance and enable their use in various applications.

Simulation

Details of Magnesium Alloy
Name : AZ61A Magnesium Alloy
Chemical Composition : By Wt%

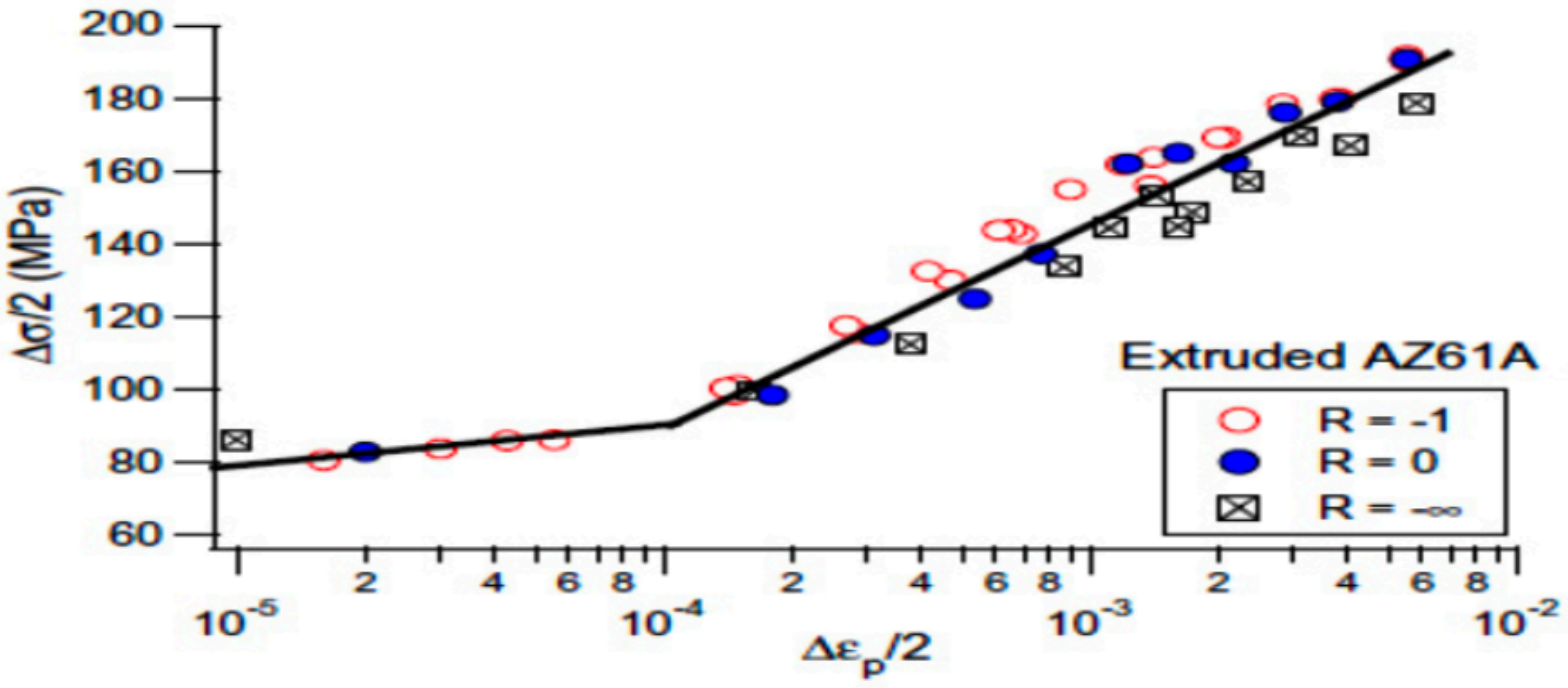
Al	Mn	Si	Cu	Zn	Fe	Ni	Other Impurities	Mg
6.5	0.325	0.1	0.05	0.95	0.005	0.005	0.3	Balance



Circular Specimen Sheet

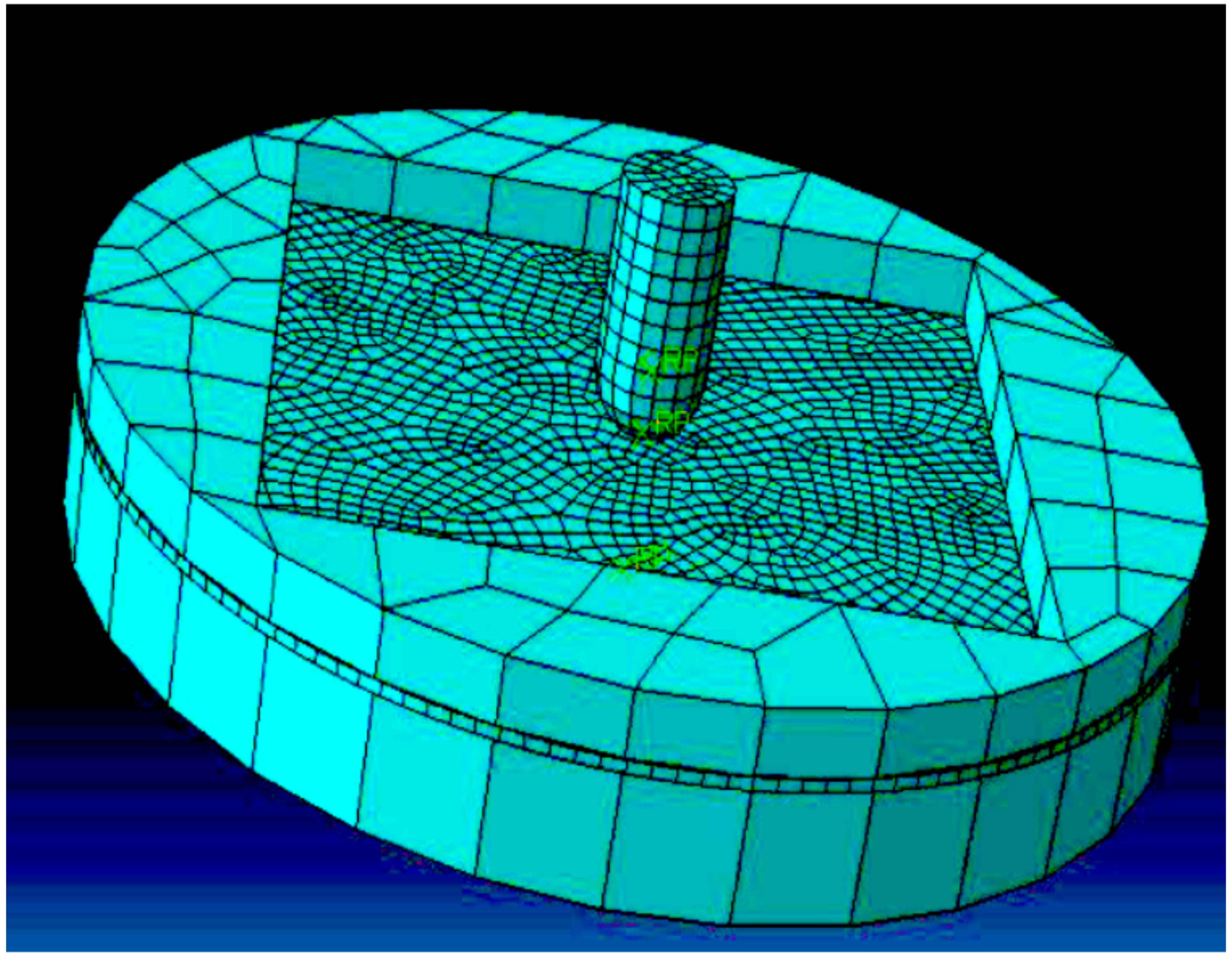
Details of Magnesium Alloy

Diamete : 100mm
Thickness : 1mm
Tensile Strength : 220-260 MN/m^2
Density : 1.718g/cm^3
E : 43.3 GPa
G : 16.4 GPa
$\sigma_{yt(Min)}$: 192 MPa
$\sigma_{yt(Max)}$: 120 MPa
S_{ut} : 279 MPa
Poisson's ratio : 0.35
Melting Point : 650^0C
Boiling Point : 1107^0C

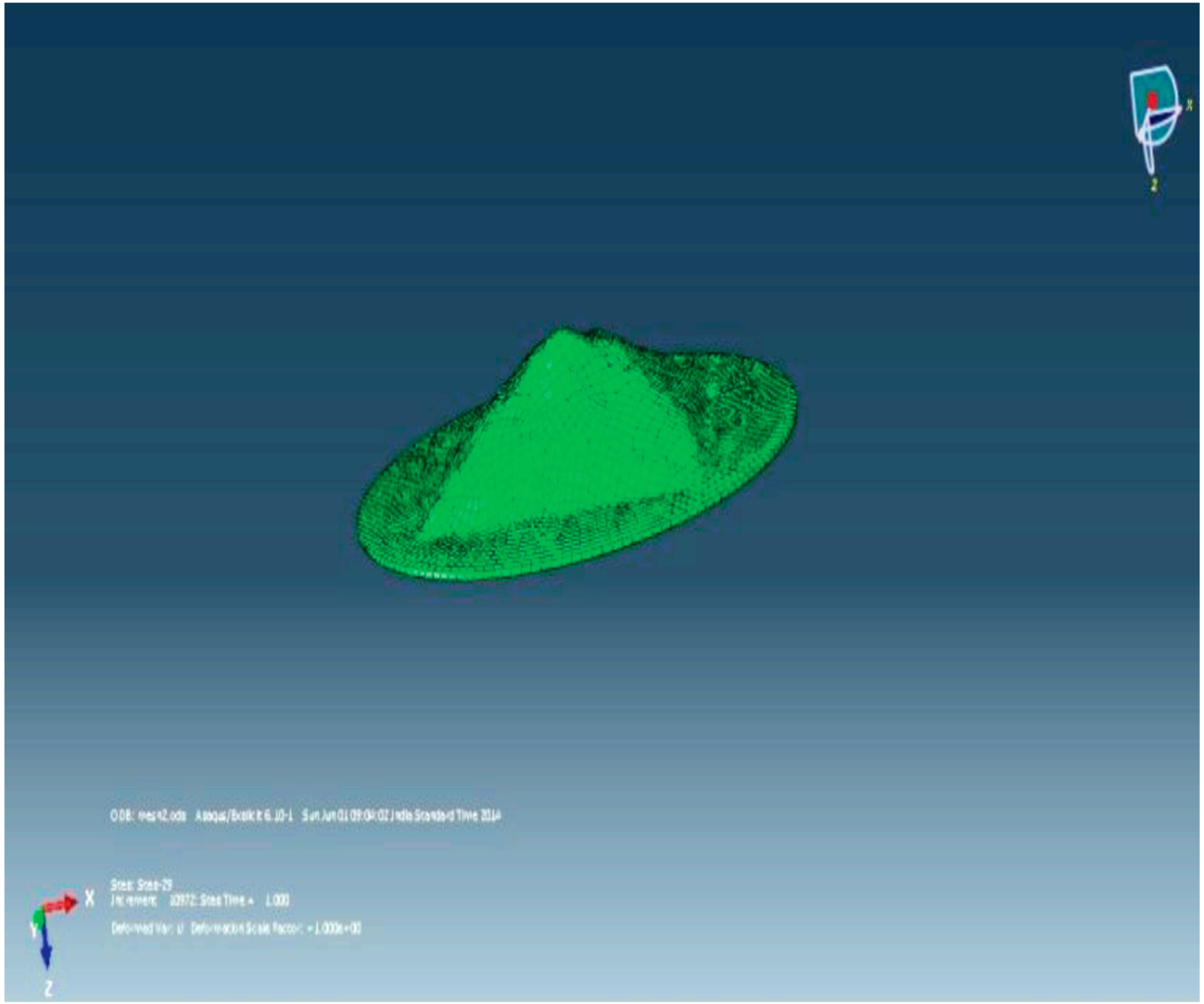


Yield Stress Vs Plastic Strain Curve

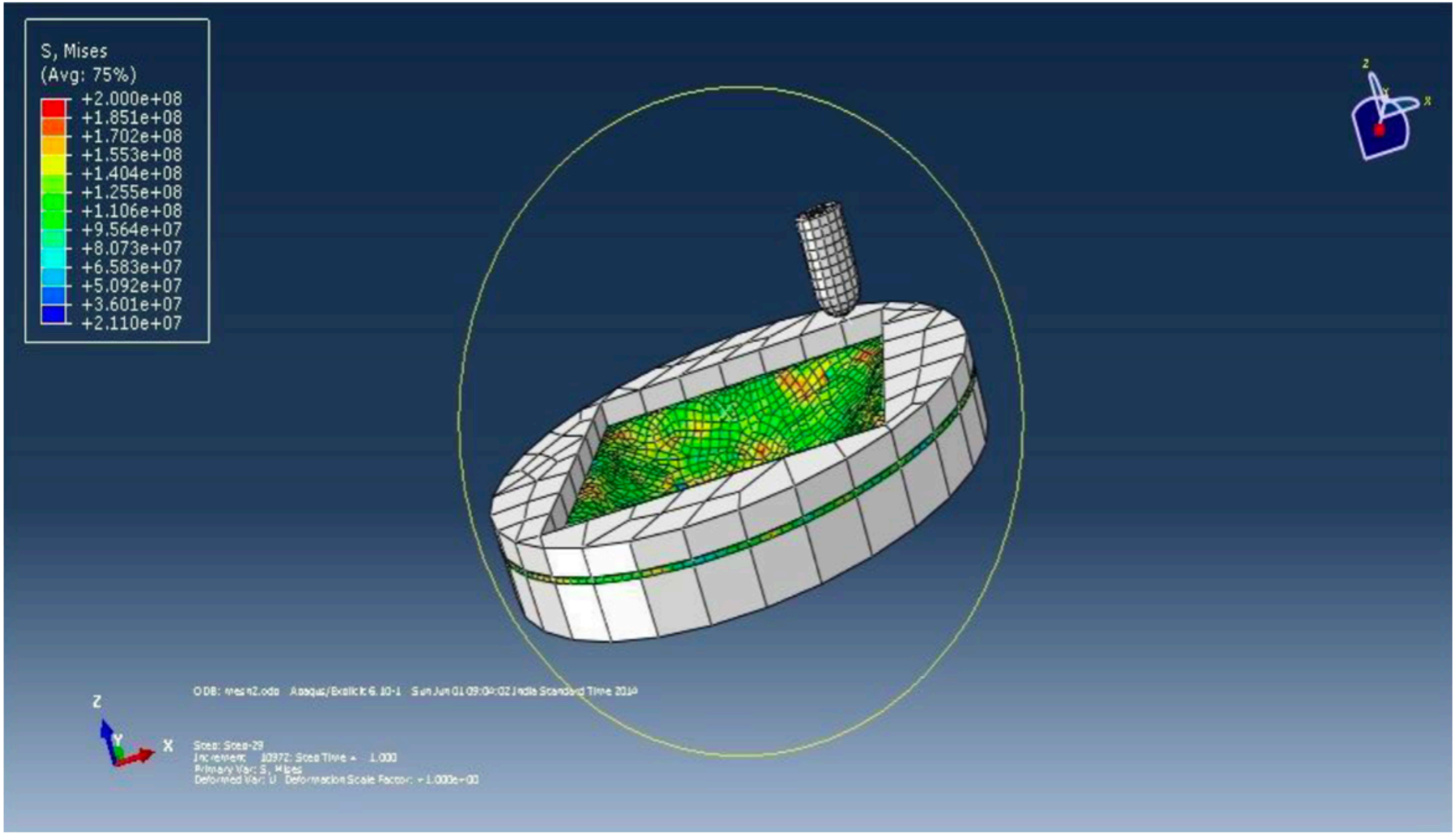
The parts, tool, blank holder, die are taken as discret rigid element and geometric order as linear. The element type is quad R3D4-4 Nodes 3-Bilinear. The sheet is taken as deformable type and linear Hex C3D8R. 8-node linear brick with global size of the sheet given for meshing is 2. Total number of steps used for the analysis is 29. The Dynamic/Explicit method is used to solve the problem.



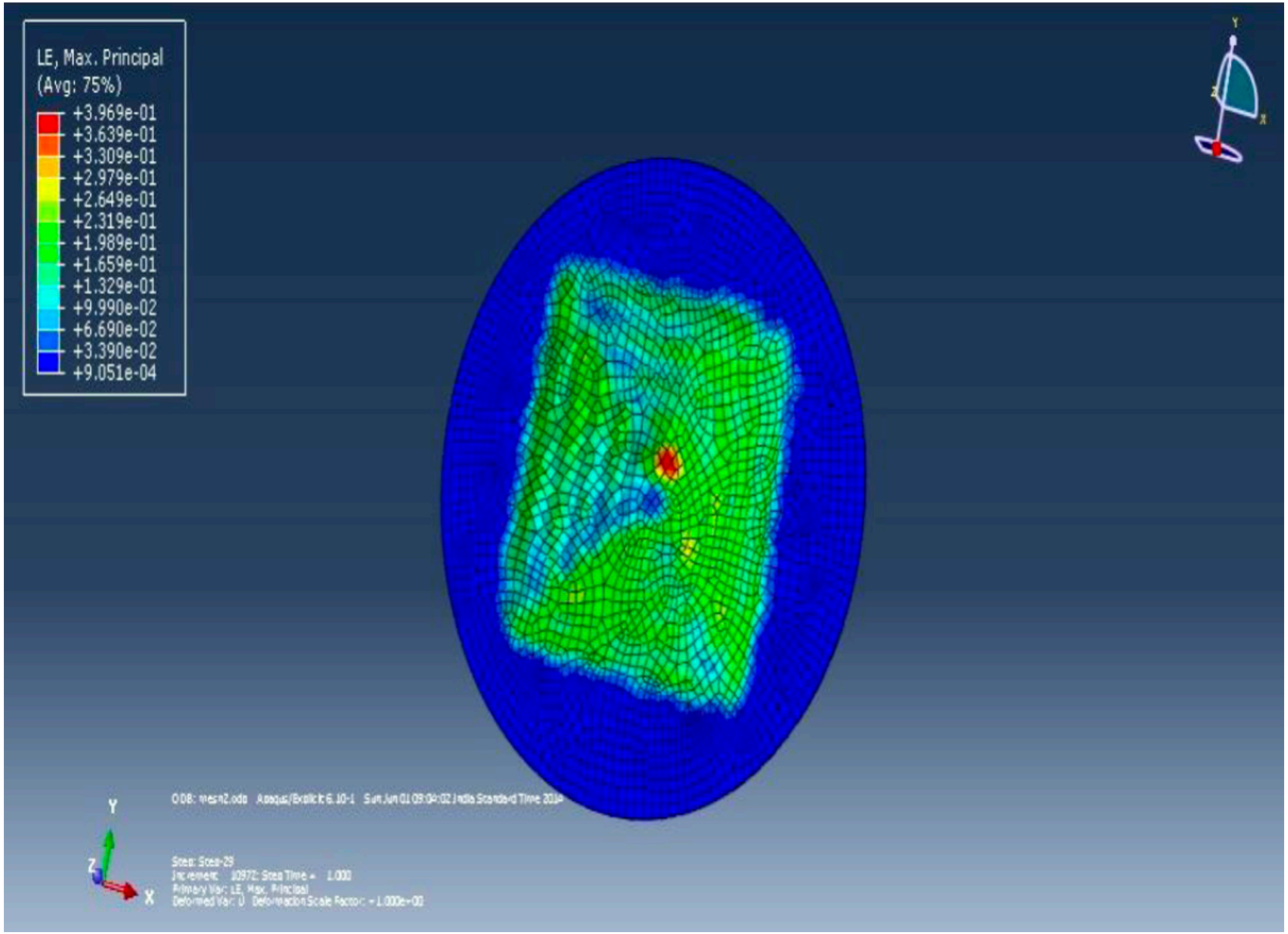
Generated Mesh with ABAQUS



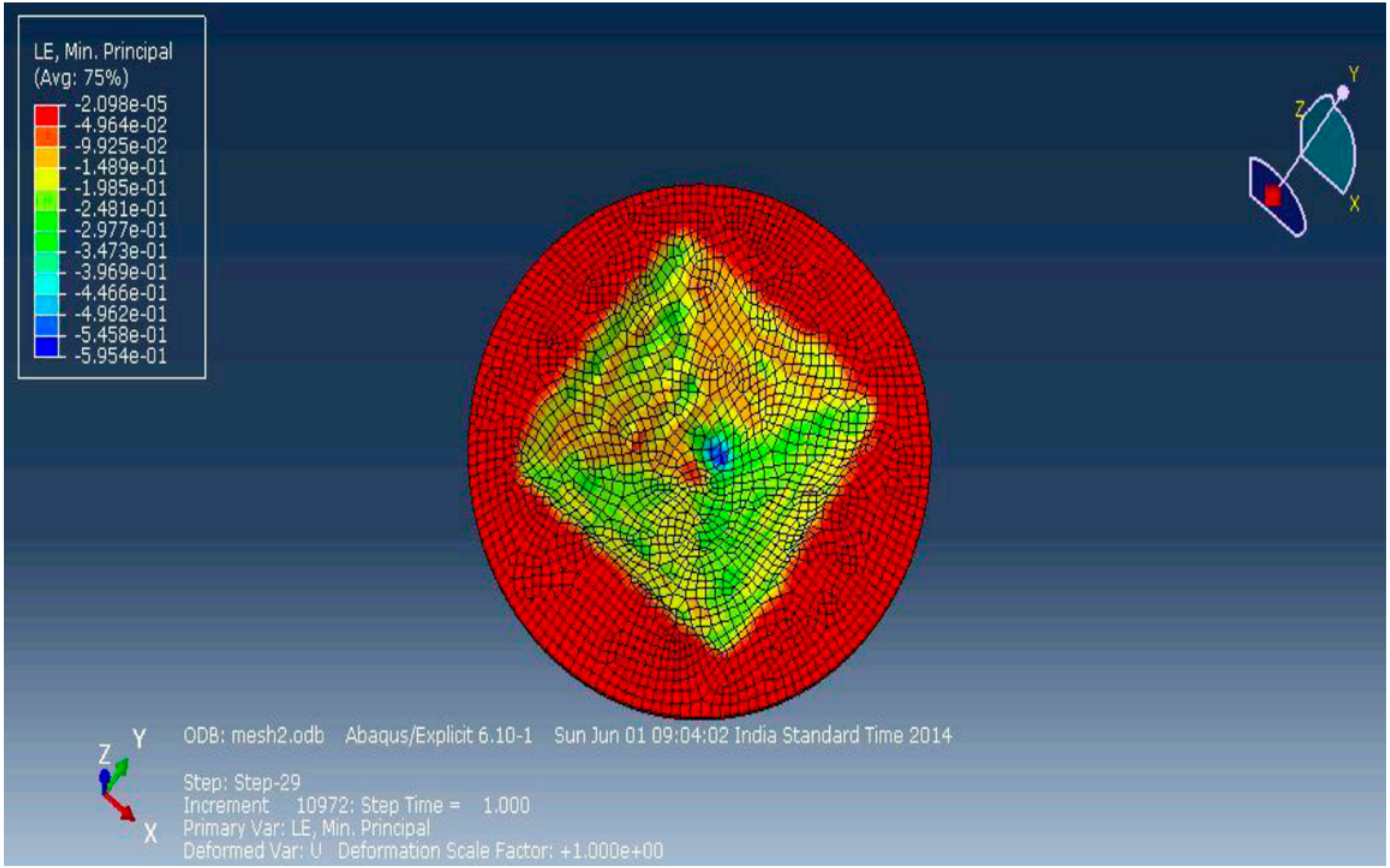
Deformed Shape of the Sheet



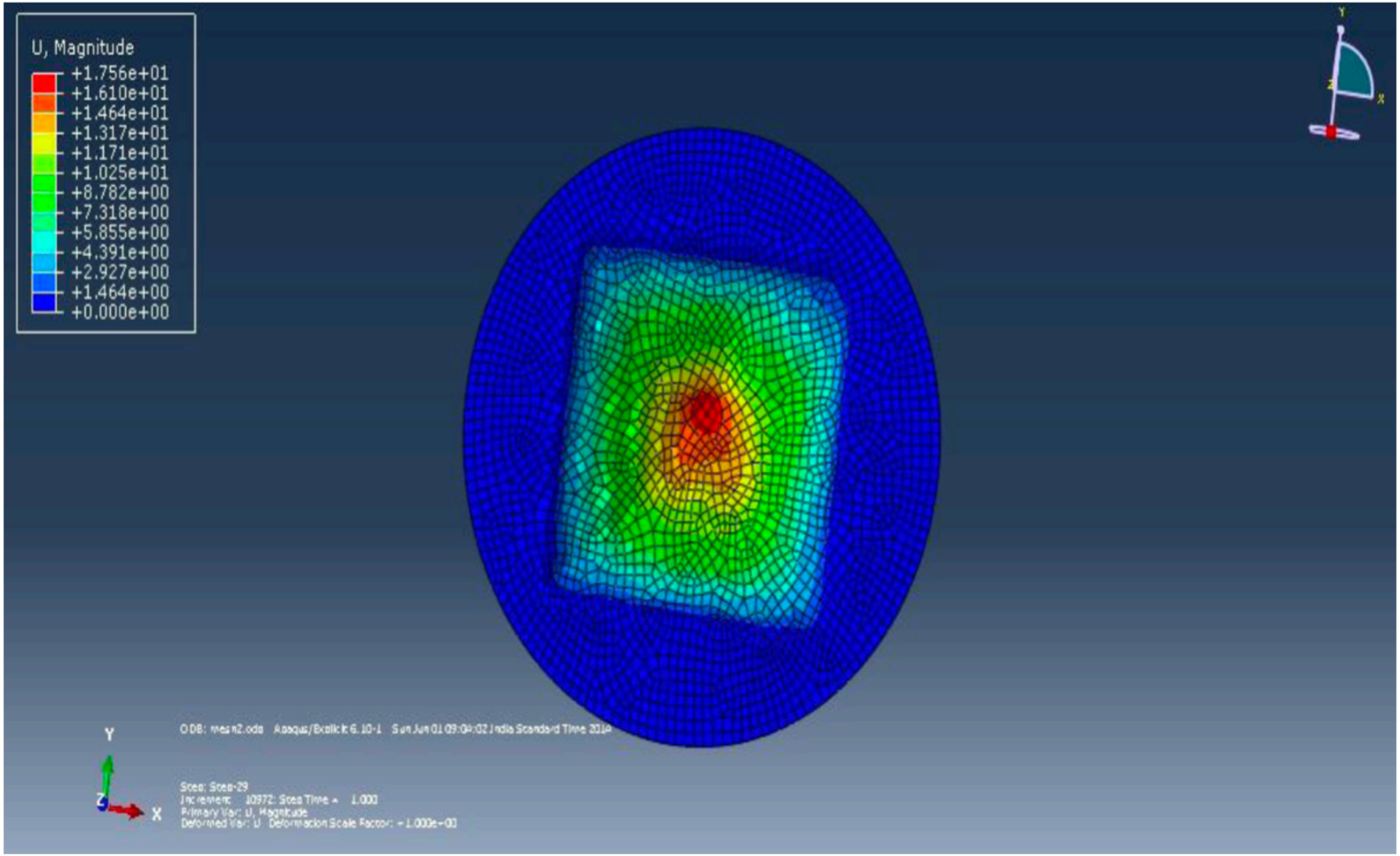
Stress Distribution



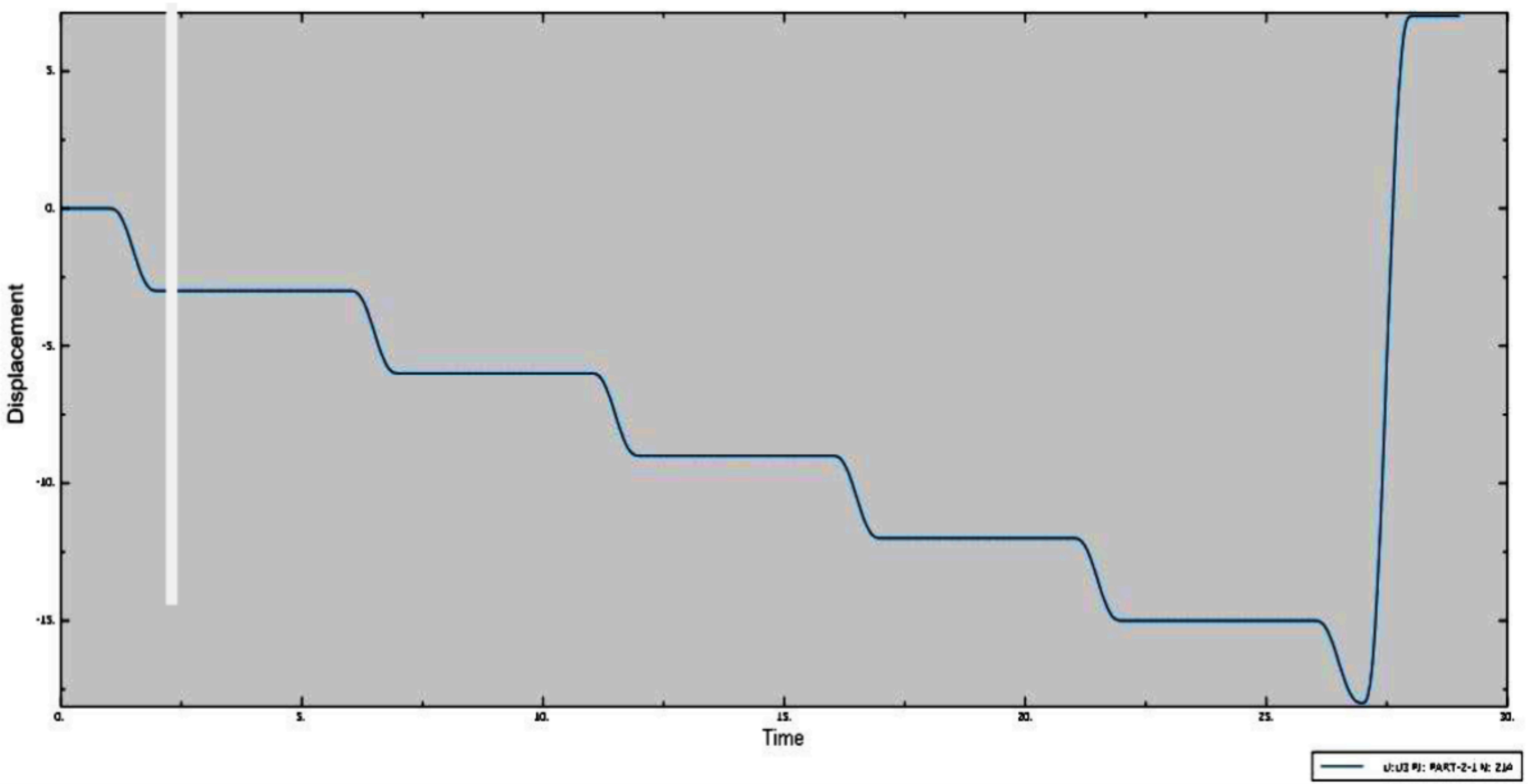
Maximum Logarithmic Principal Strain



Minimum Logarithmic Principal Strain



Nodal Displacement



Displacement vs Time

Result

The contour plots shown illustrate the evolution of the damage field and the propagation cracks in the field. It is evident in both plots that the stress and strain in the damage zone increases towards the shear line. The figure shows the final output of the analysis. The deformed shape is in the form of a truncated pyramid. The dies and the blank holder hold the sheet and it is restricted to move and to reduce wrinkling.

Conclusion

The simulations provide reasonable prediction of work piece deformation and strain distribution. The models were able to predict the areas in work piece that would experience thinning. The deformability of AZ61A magnesium alloy was observed by the analysis. It's found that the numerical errors are acceptable while a reduction of CPU time was observed. The tool is made as rigid material and the tool path was created and the maximal velocity of the tool is controlled by smooth STEP function.

Thank You