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# FINITE ELEMENT ANALYSIS OF CEMENTED CARBIDE DRILL BIT IN ROCK DRILLING PROCESS

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## ABSTRACT

*Drilling is probably the most important conventional mechanical process and it is the most widely used machining operation. Prediction of cutting forces for any set of cutting parameters is essential in optimal design and manufacturing of products. It has been predicted that most of the problems associated with hole making operation such as drilling can be attributed to the force generated during cutting operation. In addition prediction of force helps in design and evaluation of cutting tools.*

*Prediction of cutting forces and associated stresses developed during the drilling operation helps designers to design tools without conducting experiments. This cuts down the time and money involved in product development life cycle.*

*The objective of the work is to predict the forces and stresses generated on cemented carbide DTH (Down the Hole) drill bit in rock drilling process. The Finite Element Analysis of cemented carbide DTH drill bit in soil drilling and rock drilling process is done by modeling and analysis software's and safe stress values are suggested which is in the permissible limits.*

## 1. INTRODUCTION

DTH is short for "down-the-hole". Since the DTH method was originally developed to drill large-diameter holes downwards in surface-drilling applications, its name originated from the fact that the percussion mechanism followed the bit down into the hole. Applications were later found for the DTH method underground, where the direction of drilling is generally upwards instead of downwards.

### 1.1 Technical details

In DTH drilling, the percussion mechanism – commonly called the hammer – is located directly behind the drill bit. The drill pipes transmit the necessary feed force and rotation to hammer and bit plus compressed air or fluids for the hammer and flushing of cuttings. The drill pipes are added to the drill string successively behind the hammer as the hole gets deeper. The piston strikes the impact surface of the bit directly, while the hammer casing gives straight and stable guidance of the drill bit. This means that the impact energy does not have to pass through any joints at all. The impact energy therefore is not lost in joints allowing for much deeper percussion drilling. This is a Great breakthrough for smaller portable water well drilling rigs, that before were limited. The DTH on smaller rigs now can get same results as large heavy truck rigs. With recent advances in technology DTH hammers and bits can now be operated to run at up to 500 MPa, increasing the Rate of Penetration.

### 1.1.1 Uses

Geotechnical, Foundation/Construction, Mineral Exploration, Seismic, Blast Hole

Water Wells, Environmental Science, Oil & Gas Industry.

### 1.2 Types of drilling:

I Percussion drilling or cable tool drilling

II Direct rotary drilling

III Down-the-hole drilling

### 1.2.1 Percussion/cable tool drilling

It involves the use of heavy duty drill bit with a drill stem, drilling jar and a rope socket and is lowered through a cable on which it is run into the hole. The same is moved up and down either manually or mechanically to brake the formation with the addition of water and bring the cutting to the surface.

### 1.2.2 Rotary Drilling

In the rotary drilling the rock is made to fail by means of combination of pull down pressure on the bit and rotation power. Compressed air is used in sufficient volume to ensure minimum velocity of upward air flow that both removes drill cutting and keeps the hole bottom clean.

### 1.2.3 Down-the-hole drilling (DTH)

In DTH drilling the rock is made to fail by means of the piston that delivers the rapid impacts to the drill surface , thereby transfering energy to drill bit. The blows to the rock down hole are delivered by bit. While the rotational device ensure that the bit impacts a new rock surface with each blow. A feed force is applied to maintain a rock bit contact . Compressed air is used to remove the cutting from the hole, thereby advancing the hole depth at an efficient rate.

The piston can either be mounted out of the hole (OTH) or Down-the-hole (DTH) for quite and efficient drilling.

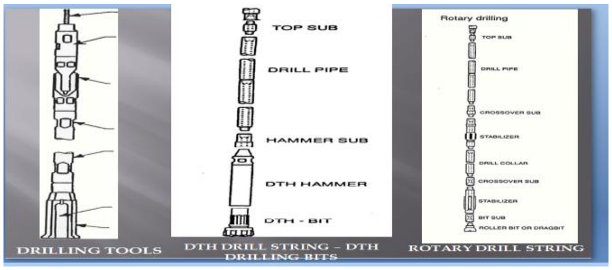



**Fig 1. Hammer and bit parts detail**

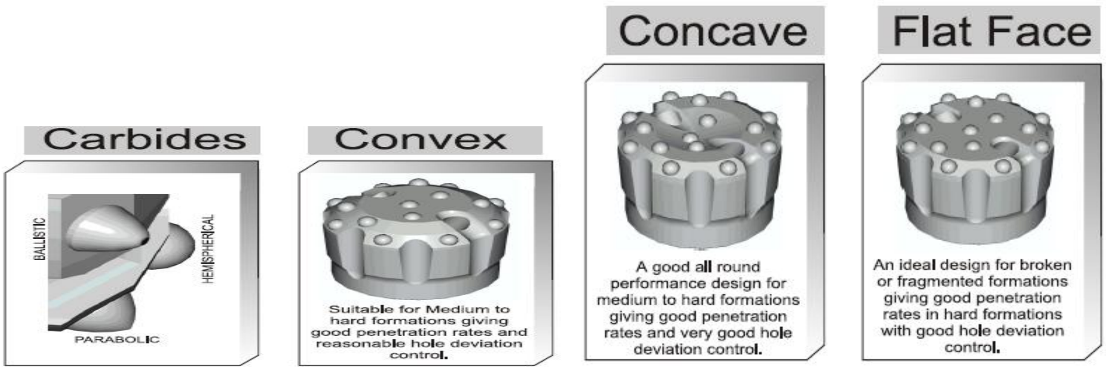



**Fig 2 Drill buttons in bit of different sizes**

**1.3 Rotation Speed & Feed Force:**

Rotational speed is largely determined by drilling conditions, typically 60-100 RPM for a 3-inch hammer. As a result of its higher piston frequency and penetration rate, the manufacturer should have a higher rotation speed and require more feed force than conventional hammers. Depending on the rock type and conditions, it may be necessary to increase rotation speed 10-15 per cent to achieve the smoothest and most efficient drilling.

**1.4 Weight on Bit:**

For efficient drilling it is important that the buttons on the face of the bit are in close contact with the rock at all times. Drilling feed weight on bit must be sufficient to keep the bit closed against the driver sub allowing the maximum amount of piston energy to be transferred to the rock.

If drilling feed weight is insufficient, the rock breaking energy stays within the hammer and will cause premature component failure.

Several problems can occur if drilling feed weight is excessive. The buttons will penetrate too deep into the rock resulting in bit face damaged, the rotation torque will increase, flushing will be reduced in softer ground and in some conditions, hole deviation could occur.

The optimum weight on bit will vary according to many conditions, such as the type of rock, bit design, rotation speed. The optimum weight on bit is best determined by the driller, but below is a guide for weights at various operating pressures.

## 1.5 Drill bit manufacturing:

The drilling bit used in DTH drilling is made of alloy steel with tungsten carbide inserts which provides cutting edges/ points to the bit. Earlier, Cross bit in which four tungsten carbide inserts were brazed in the alloy steel body of the bit in '×' position, were in common use. Now a day, the most popular type of DTH bit is the button bit deriving its name from the hemispherical shape of tungsten carbide inserts. Other shapes of the tungsten carbide inserts have been tried all over the world. However, after sustained trials, button inserts have been found most suitable and most of the manufacturers have standardized on the hemispherical shape.

## 1.6 Cemented Carbide

Cemented Carbides, CC, also called Tungsten Carbides, hard metals or cermet, are hard composite materials consisting of at least two phases. The required constituents of the CC are a ceramic hard phase, called α- or γ-phase, and a metallic binder, β-phase. Different types of carbides can be used as the hard phase, but mostly used is the Tungsten carbide, WC. This phase is usually of high hardness but is brittle, which causes a problem if it would be used without a binder phase. The aim with the binder phase is to glue the grains of the carbide together and give the composite toughness without losing too much of its hardness. The increased toughness is achieved by lowering internal friction between the carbide grains. Historically Iron and Cobalt have been used for this purpose, although now Co is almost exclusively the main binder material.

## 1.7 Manufacturing of Tungsten carbide

### 1.7.1 Powder manufacture-

The first step in manufacturing cemented carbide is to reduce tungsten carbide and cobalt oxide powder by intimately mixing them with lamp black and heat the same in a current of hydrogen. The size of metallic powder obtained is controlled by the heating time, temperature and rate of hydrogen flow. The tungsten powder is then ground and mixed with a weighed quantity of lamp black and the mixture is heated for several hours in a reducing atmosphere at a temperature of 1600°C, by this process tungsten is converted into tungsten carbide. This powder is then ground to a fineness of 20 microns or less, process is commonly called chemical reduction.

### 1.7.2 Powder mixing-

In this stage to mix the tungsten carbide and cobalt powder in suitable proportion in a suitable mixing machine. When powder is not properly mixed segregation is likely to occur.

### 1.7.3 Compacting of powder-

Mixture is then compacted in alloy steel dies at a pressure of about 40 kg/sq. mm. The compacting operation should be rapid to prevent the possibility of seizure. In order to assist in obtaining a good finished product, glycerine is used during the mixing of powder.

### 1.7.4 Sintering-

The sintering is done in two stages. The preliminary sintering is done at a temperature of about 900°C in a controlled atmosphere. These products are then shaped to the exact size by machining. The final sintering is done at a temperature of about 1450°C, the sintering time being about 2 hours. Hydrogen atmosphere is maintained during final sintering. The cooling down is gradual and is done in the furnace itself. Cobalt powder is used for bonding the tungsten carbide powder. Cobalt fuses at the sintering temperature, whereas the tungsten carbide remains intact. The product is known as cemented tungsten carbide.

Tungsten carbide products are pre sintered in a separate furnace at a low temperature. The object of pre sintering is to give the product sufficient strength so that it can be handled properly in high temperature sintering plant

### 1.7.5 Fabrication

The fabrication of cemented carbides is done by powder metallurgy since WC has a high melting point, 2800°C, and forging it would cause segregation of cobalt and the carbide grains. The first step in production is to mill or mix the raw materials down to the wanted grain size in large mills. Here WC, Co, milling bodies, milling fluid and a polymeric pressing aid are introduced and milled together. Milling fluid is used so that the milled substances do not form oxides. The polymeric pressing aid is usually Wax or Poly Ethylene Glycol, PEG, and works as glue that holds particles together during the following agglomeration, drying and pressing. The drying rids the mixture of the milling fluid and makes WC grains and Co form small homogeneous balls withthe PEG, called agglomerates. The agglomerated powder is introduced in a press and pressed to a body that can withstand handling, called green body. The green bodies are then sintered in two steps. Firstly the PEG is de-binded in a temperature range up to 300-500°C depending on the additive often using hydrogen gas. The next step is melting of the binder phase at 1300-1400° in vacuum or argon. During the sintering the body is compacted and the volume is decreased by about 45%. This production technique gives good homogeneous materials with a small porosity of about 1-2%. The amount of carbon in the body that is to be sintered is key to what the result of the sintering is. Too much carbon gives graphite formation, and too little carbon of the η-phase, a M6C structure. Usually the carbon amount window I about 0.06% fora 10% Co grade and 0.03% for a 6w%Co grade, which is a fairly small window that is crucial not to miss.

## 1.8 Characterization

Cemented carbides are, besides dimensions and weight, characterized by the grain size, the amount of cobalt and any additives. These three factors can be varied to achieve different hardness wear resistance, toughness, etc. It is shown that to increase grain size in order to gain wear resistance, the amount of cobalt has to be decreased to maintain the same hardness and toughness. So it is important to know the mean grain size and the cobalt content of the material. The magnetic properties of cobalt can be used for these measurements. By measuring the strength of the coercive field, a value for the mean free path in Co is measured, giving an indirect figure for the size of the carbide grains. The amount of cobalt is measured by the strength of the magnetizing field since it varies with the amount of cobalt in cemented carbides. Two other important attributes are the hardness and toughness of the cemented carbide, which are usually measured by a Vickers indentation test and measuring the cracks formed at the corners thus Palmquist toughness. Bend tests are also performed in order to determine crack lengths and defects. These tests are commonly used, but care should be taken to what information they give since they are not good at showing micro structural aspects of cemented carbides, meaning that cemented carbides with the same hardness but different carbide grain sizes are hard to separate.

## 1.9 Variation of load

The results from the testing are shown in figure. As can be seen in the graph, there is not a clear correlation between the load and the worn mass of the sample.

**Table-1**

| No. | Load Applied (Kg) | Mass Loss(gms) with Water | Mass Loss(gms) without Water |
|---|---|---|---|
| 1. | 0 | 0.00 | 0.00 |
| 2. | 5 | 0.020 | 0.012 |
| 3. | 10 | 0.008 | 0.026 |
| 4. | 12 | 0.0024 | 0.022 |
| 5. | 15 | 0.013 | 0.020 |
| 6. | 17.5 | 0.023 | 0.016 |
| 7. | 20 | 0.026 | 0.022 |

Wear as a function of load at (30 Min.) sample tested with and without water

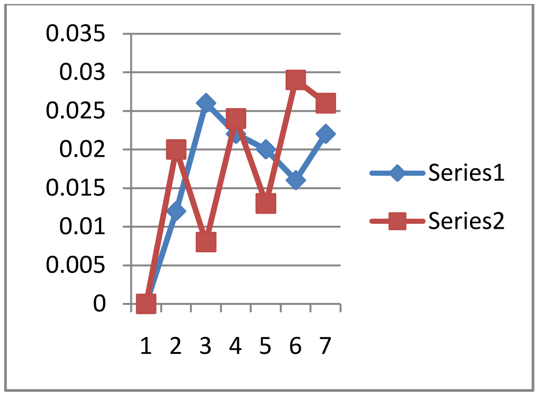
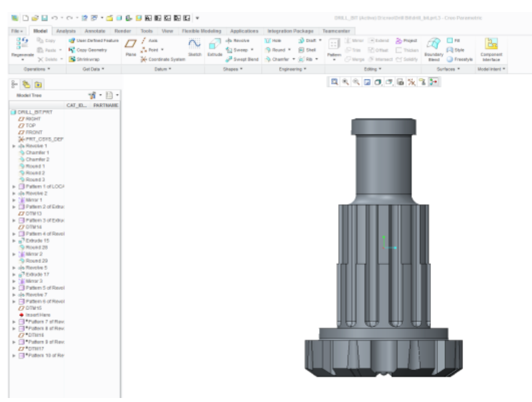
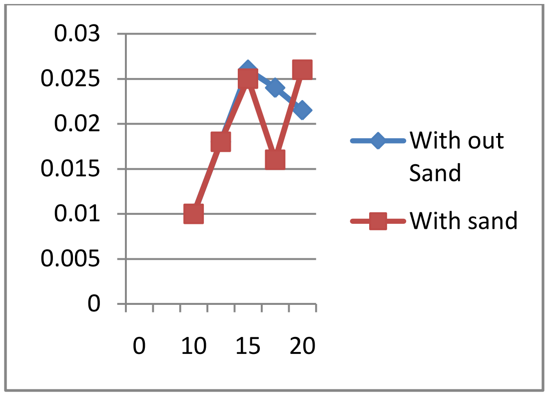



**Table-2**

| S. No. | Load Applied (Kg) | Mass Loss(grams) with Sand | Mass Loss(grams) without Sand |
|---|---|---|---|
| 1. | 0 | 0.00 | 0.00 |
| 2. | 5 | 0.00 | 0.00 |
| 3. | 10 | 0.01 | 0.01 |
| 4. | 12 | 0.018 | 0.018 |
| 5. | 15 | 0.025 | 0.026 |
| 6. | 17.5 | 0.016 | 0.024 |
| 7. | 20 | 0.026 | 0.0215 |

**Wear as a function of load at (30 Min.) sample tested with and without sand**



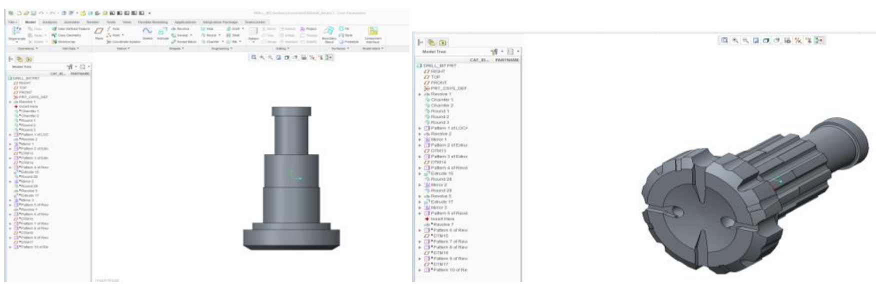



**Wear as a function of load at (30 Min.) sample tested with and without sand used as $SiO_2$**

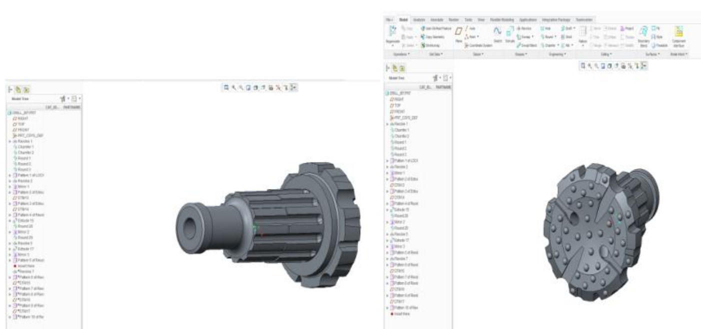
## 2.0 FINITE ELEMENT ANALYSIS

### 2.1 Modeling of Drill Bit:

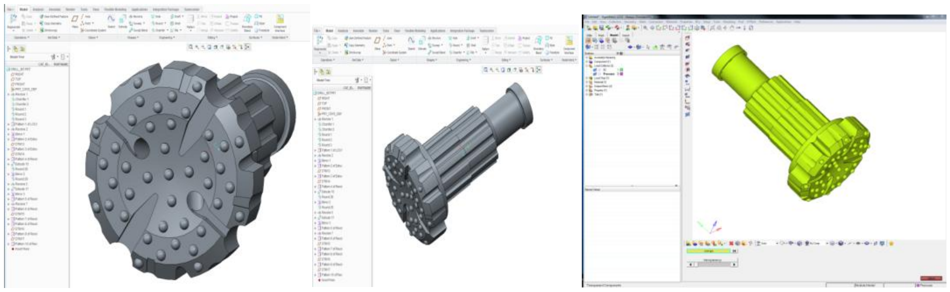
- Prepare the base model by using revolve option with the base dimensions:



- Apply the base cuts and required slots:



Add teeth by using revolve and pattern options



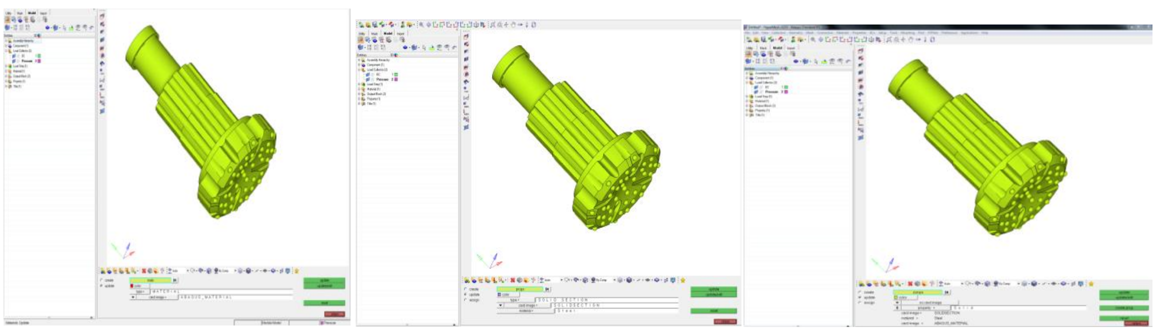
Once the model is prepared save it to step file

Create a material with name steel required material property of EN36C ASTM E415 material properties

Density: $7.8e^{-9}$ ton/meter$^3$

Young's Modulus: 6.5 $e^5$

Poison's Ratio: 0.3



Create the property with by name Solid Section (for Example):

- Create a component and attach the previously created property to the component created

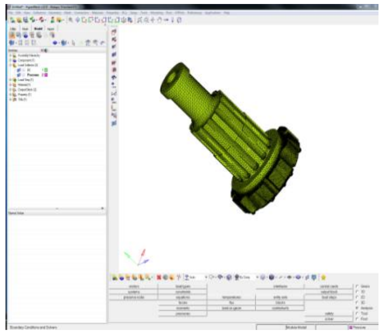
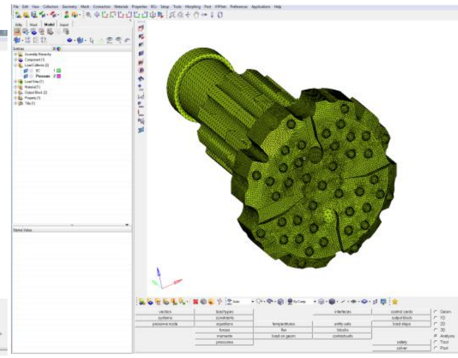
**2.2 Create the mesh:**

Create the mesh with a bit less in size (2mm) at the tooth as it is the area of interest of the project And mesh (10-5mm) of uniform and mapped mesh in other areas (at the top as shown in the first image of meshed component).

Total no. of elements: 354992

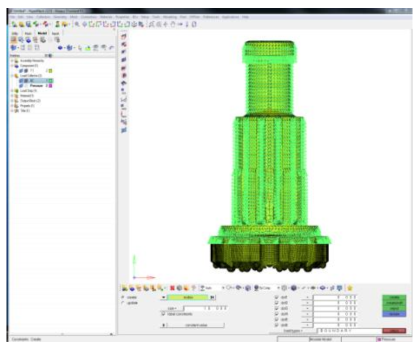
Total no. of nodes: 76054

Type of element: Tetra4 (first order elements)

### 2.3 Creating Boundary Conditions:

Create the Boundary Condition by fixing the component nodes (outward as shown in the figure) with all degrees of freedom.



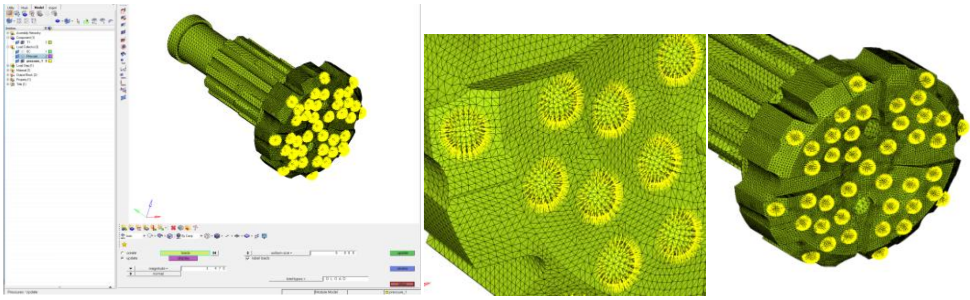
And attach the boundary condition property the constraints

### 2.4 Applying the FORCES:

There will be 2 types conditions that a drill bit faces while it is drilling with the soil the total force falls all around the tooth surface UNIFORMLY as pressure, while it is drilling the stone layer the force as a pressure falls NON-Uniformly where some nodes will be experiencing the highest amount of forces. The maximum amount of forces that can exert is about 350MPa by considering the Factor of Safety we have taken it for 500MPa.

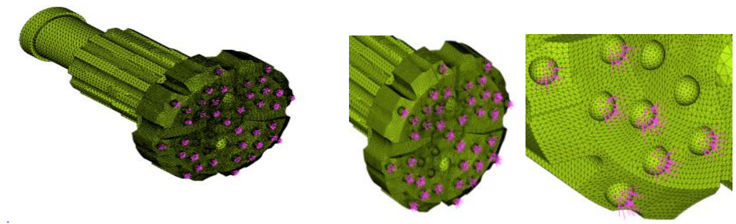
### 2.5 Applying the force for soil drilling condition:

Apply the pressure all over the tooth by selecting all the nodes (outside the face) and apply the pressure of 500MPa normal to the face. As shown in the figure.



## 2.6 Applying the Force for Rock Drilling Condition:

As the force exerted is not uniform in this condition. And the whole force acts as an impulse force randomly on certain nodes as shown in the figure below. And there might be chances for failure of the Drill bit tooth.

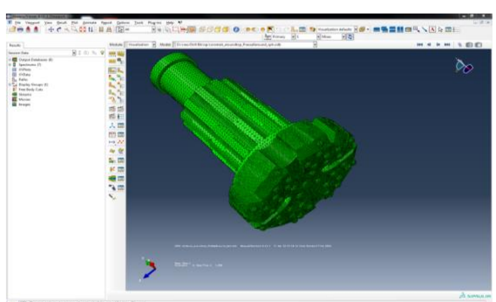


- Export the created meshed file in the .inp format which can be executed in the ABAQUS software

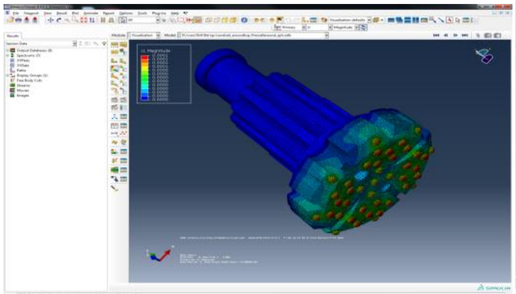
Solve the files in Abaqus using command prompt as shown in the figure.

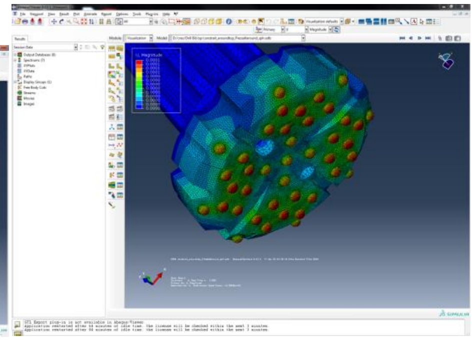
## 3.0 RESULTS AND DISCUSSION

**Case1: Soil Drilling:** Import the .odb file in the Abaqus Viewer

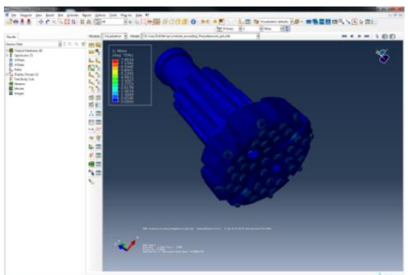


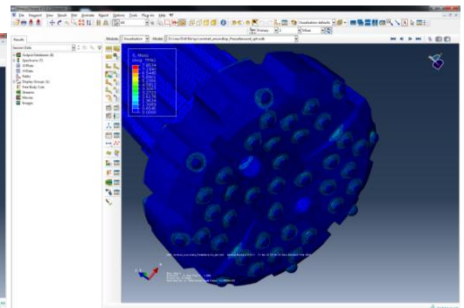
Case 1: (conditions of drilling Soil) Displacement:





**Stress Plots (Von Misses Stress):**





**Observations found in Case 1:**

Deformation: 0.001mm

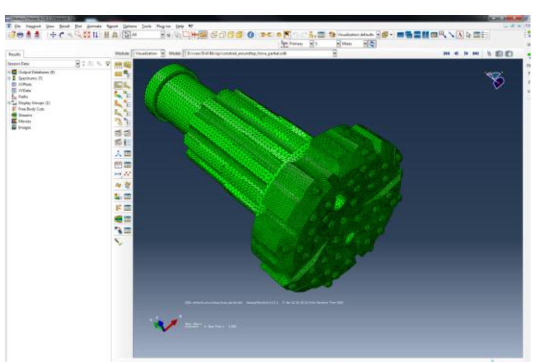
Von Misses Stress: 7.85 MPa

Max. Permissible stress allowed by the material: 340 MPa

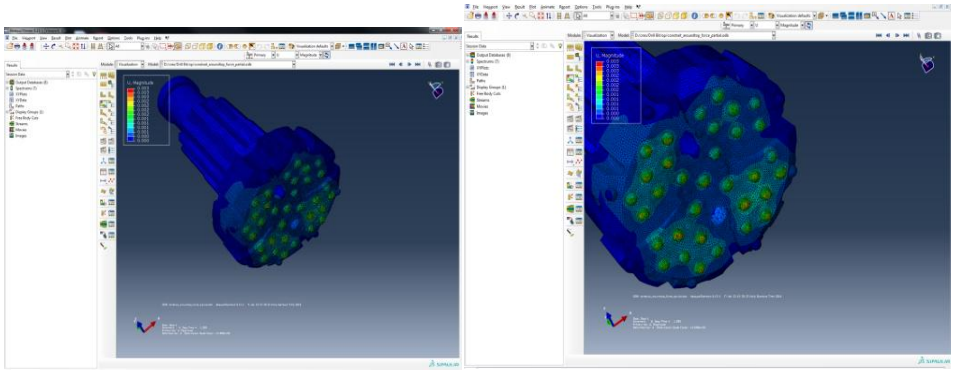
Hence the Design is safe for soil Drilling condition

**Case 2 (Drilling of Rock):**

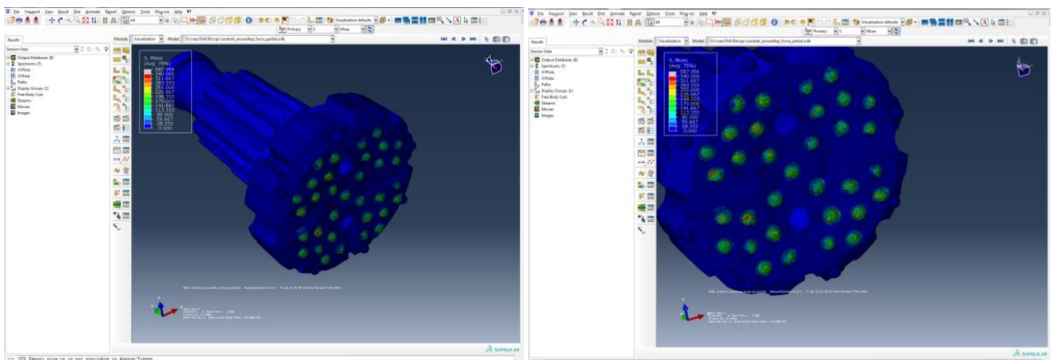
Import the .odb file of the case 2 in Abaqus viewer

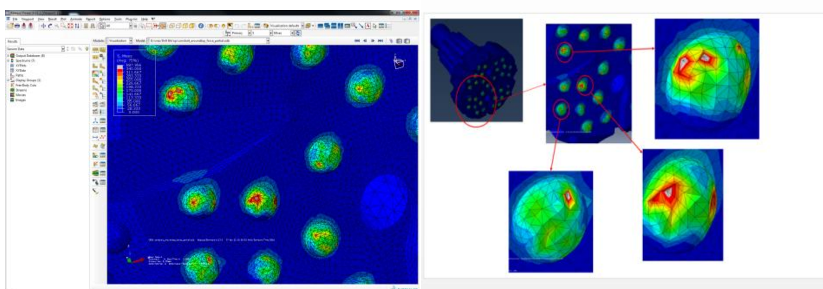


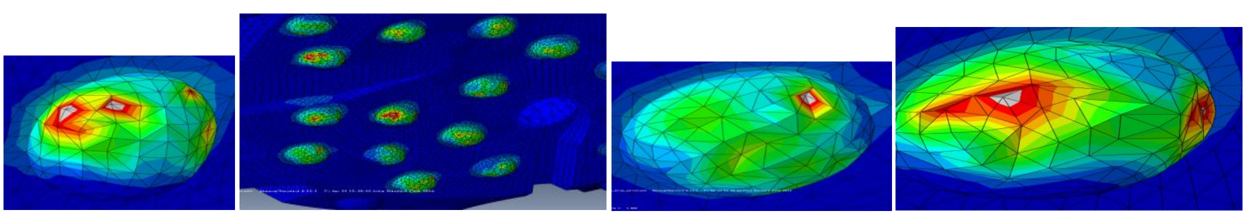
## Displacement:



## Stress (VonMisses):







## Observations found in case 2 :

Displacement : 0.03mm

Stress (Von Misses stress): 587 MPa

As the max permissible stress allowed by the material is 340 MPa we have found some stresses in the tooth with stresses above the permissible limit. As seen in the above pictures.

Hence the drillbit might fail in some tooth as shown in the figure above.

## 4. CONCLUSION

This work has focused on reviewing literature and creating a test method that can distinguish between different cemented carbides and create wear test in a situation comparable to that of rock drilling and to find stresses generated on cemented carbide DTH (Down The Hole) drill bit in rock drilling process, The Finite Element Analysis of cemented carbide DTH drill bit in soil drilling and rock drilling process is done by modeling and analysis software's and safe stress values are suggested which is in the permissible limits. In that respect, the test created was successful. Many conclusions can be drawn from literature, the test rig, the results and analysis.

- By considering factor of safety the maximum allowable stress in rock drilling process is 500 MPa, based on analysis the drill bit experiencing the maximum stress as 340 MPa which is in safe limits.
- In soil working conditions the drill bit displacement is 0.001mm and stress induced is 7.85 MPa which is in safe working condition.
- In rock drilling the displacement is 0.03mm and stress induced is 587 MPa which is above the permissible limit hence drill bit might fail at some tooth.
- The literature shows a lack of wear tests methods for cemented carbides involving the right surfaces and abrasive media for the rock mining application.
- Using slurry was easier to control than having separate sand and water feeds.
- The test method is shown to be a fast way of evaluating different cemented carbides, with tests of only 90 seconds.
- The results show that the counter body and sand are important to the results. It is crucial to know what stone is used before the testing and harder rock gives less wear on the drill bit.

## 5 Scope of future work:

- Measure the stress induced in drill bit by changing composition, micro structure and nature of loading.
- The most important improvements are to be able to measure the load on the sample, and a way of determining the volume that the counter body has lost.
- Future tests should include a variation of the rotational speed of the stone, as well as how fast the sample moves along the cylinder.
- A study of the counter body and the abrasives used would also be interesting to perform.

- Changing the microstructure of the cemented carbide should be looked at as well, especially the grain size distribution

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