THERMO-MECHANICAL CYCLIC LOADING OF SHEAR BLADES

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CONTENTS

ABSTRACT

Keywords: Shear blade, Deform-3D, Stellite21, cooling channel.

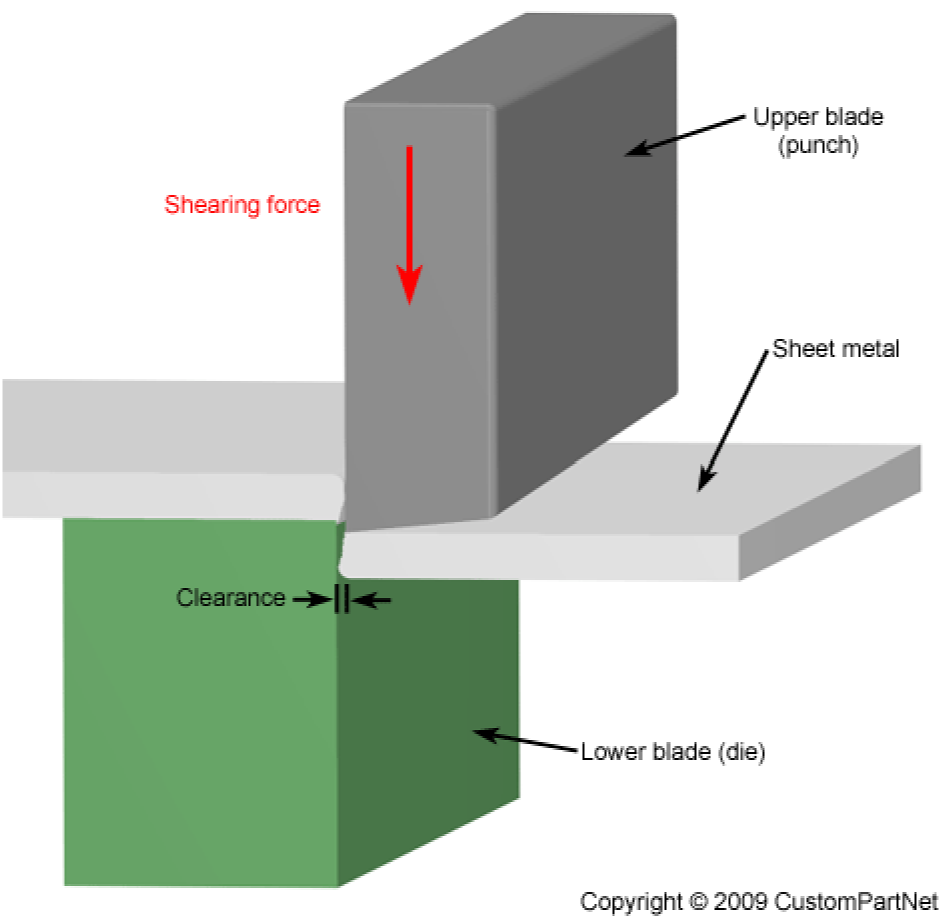
Determination of the maximum temperature during machining process and its distribution along the surface as well as inside the shear blade (cutting tool) is important as it influences the tool life as well as the machined part. In this project, the maximum temperature and the temperature distribution of the shear blades at the end of ten machining operations has been determined through simulations of the blade under constant mechanical loading conditions using the software DEFORM-3D.

Shear blades in machining industry are used to cut the hot long cylindrical bars into required sizes of blankets. These are made up of a material called Stellite21. The maximum temperature was found at the central patch regions of the shear blades indicating the maximum contact it bears with the hot cylindrical bar. The maximum temperature was found to be 598C. This determination shall be used to design a new cooling channel for the shear blade so as to account for a better tool life.

Introduction

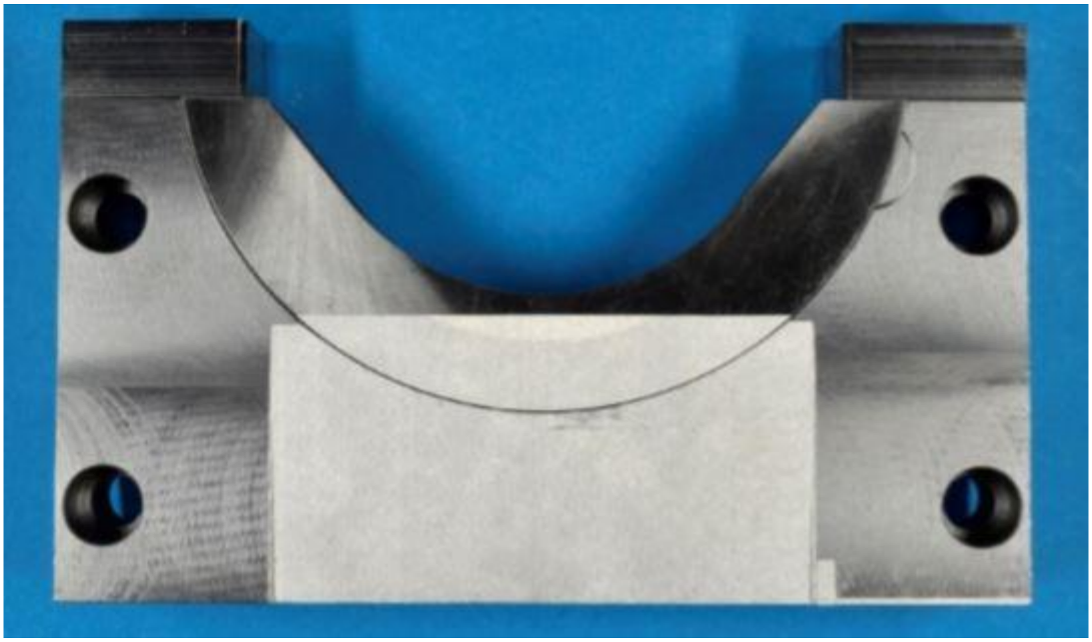
1 Hot Metal Shearing

Hot metal shearing process, as the name suggests, the metal specimen is heated to a red hot condition where it reaches to its plastic limit closely is subjected to shearing process with the help of a pair of shear blades. At the end of the operation, we obtain the required sizes of the billets. The metal specimen will be of cylindrical shape and the blades, more often in rectangular cross section.



SHEAR BLADES:

The cutting tools used for the shearing process are the Shear blades. Figure 2 depicts the shear blades. They must be harder than the work material to perform machining. Two layers of metal can be observed from figure2. The layer above is known as hard facing and the other is known as Base. The hard facing is introduced so as to account for the tool life. After many cuts, the blade surface gets worn out and the tool wear can be seen which effects the



Machining operation drastically leading to improper shearing, less finishing of the blankets etc. In order to minimize the above, **STELLITE21** is used as hard facing material. It is coated above the base material.

STELLITE:

It is used as a hard facing material in the manufacture of shear blades. It is an alloy which contains range of Cobalt – Chromium alloys. It is used for wear resistance. It may also contain Tungsten or Molybdenum and a small but important amount of carbon.

Reference Standard	Chemical Composition								
	Co	Cr	W	C	Ni	Mo	Fe	Si	Others
Stellite 1	Bal.	30	13	2.45	< 3.0	< 1.0	< 3.0	< 1.0	< 0.5
Stellite 6	Bal.	29	4-5	1.20	< 3.0	< 1.0	< 3.0	< 2.0	< 0.5
Stellite 12	Bal.	30	8.5	1.4-1.8	< 3.0	< 1.0	< 3.0	< 2.0	< 0.5
Stellite 21	Bal.	27	0.20	0.25	3.0	5.2	< 3.0	< 1.5	< 0.5

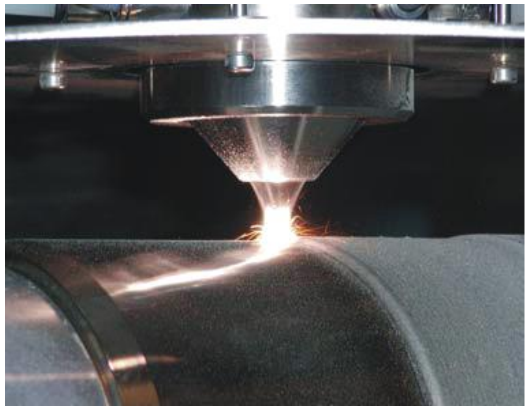
Stellite21 is primarily used as hard facing material. It contains 3% of nickel, 22% of chromium, 2.9% of Iron, 5.2% of molybdenum, 3.65% niobium, balanced Cobalt, Carbon 0.2 to 0.35%. Each element in the above composition imparts a particular characteristic to the Stellite21. Carbon content is less because of its effect on melting point of the material. The melting point of the material decreases as the carbon content increases. Not only the melting point, it also effects the ductility of the material as more content of carbon imparts more brittleness to the material. Hence carbon content is less to make the material strong at elevated temperatures. At high temperatures during machining, the blade undergoes oxidation, which on letting go causes tool wear. To minimize this effect or to build up the resistance against oxidation at elevated temperatures Chromium is introduced to Nickel. Similarly, at elevated temperatures the blades may also undergo reduction. To minimize this effect or to build up the resistance against reduction in acids Molybdenum is added to nickel. Same is the case with the addition of Tungsten. All these elements impart resistance against corrosion to stellite21.

Stellite21 can work at elevated temperatures which comes up about to 1200 to 1240C. Nickel imparts ductility and toughness to cast iron, hardness, corrosion resistance and strength at high temperatures. Nickel when alloys with nonferrous elements it imparts whiteness, magnetism, electrical resistance and control of expansion.

Stellite is a family of completely nonmagnetic and corrosion resistant cobalt alloys of various compositions. They are difficult to machine due to their harness. So they are generally casted. They have high melting point due to the presence of Cobalt and Chromium.

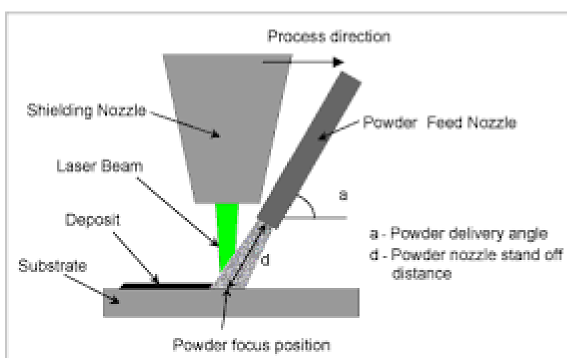
Laser deposition technology:

The shear blades are manufactured by Laser Deposition Method. LDT, which stands for Laser Deposition Technology, is an additive process that is used to build freeform fabrications, repair metal components typically considered non-repairable by conventional techniques, or strategically add features to forgings or castings. All of these capabilities come directly from CAD data. No hard tooling changes are required.



LDT deposits exhibit excellent material properties. These material properties, combined with the flexibility of the process, significantly lower overall production costs. When used for manufacturing and the production of prototypes, the LDT process greatly reduces product development time.

First, a 3D CAD file is created that defines the component that is to be built. Next, the system software uses this file to slice the piece into numerous horizontal sections and then creates a tool path for each layer. This tool path is followed by the laser as the piece is created, layer by layer. The build takes place in a controlled environment chamber with less than 10 parts-per-million oxygen. Once the chamber is prepared, the build can begin.

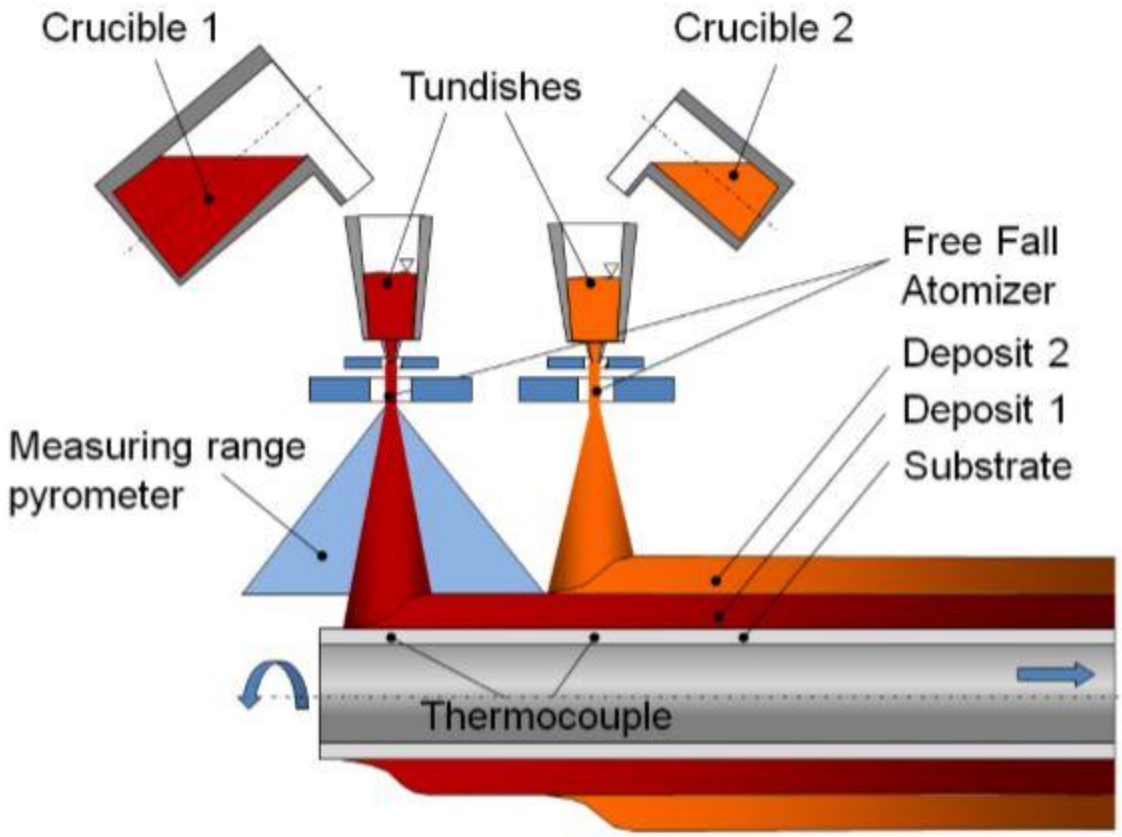


The laser fires and creates a melt pool on the surface of the target plate. A stream of powered metal is delivered into the melt pool. When the powdered metal impacts the melt pool, it is absorbed into the melt pool and creates a weld bead. Fusing multiple layers together generates a 3D solid metallic build. A variety of alloys can be used in this process including tool steels, stainless steels, nickel, cobalt and titanium alloys. Deposit quality and consistency is of primary importance for all laser deposits. Weld beads are produced in a very low oxygen environment with a very small laser spot size and relatively high travel speeds. The laser deposits have extremely high cooling rates. These cooling rates generate a very small localized heat effect zone thus minimizing distortion. Also the high cooling rates result in laser deposits that have a very fine microstructure. Therefore, the deposits typically have similar mechanical and physical properties compared to wrought products.

But at the end LDT also has some disadvantages as it allows the formation of heat affected zones where we can observe minor pores and cracks which affect the tool life when the shear blades are in operation.

Spray forming method:

Shear blades are also manufactured by spray forming method. Spray forming, also known as spray casting, spray deposition and in-situ compaction, is a method of casting near net shape metal components with homogeneous microstructures via the deposition of semi-solid sprayed droplets onto a shaped substrate. In spray forming an alloy is melted, normally in an induction furnace, then the molten metal is slowly poured through a conical tundish into a small-bore ceramic nozzle. The molten metal exits the furnace as a thin free-falling stream and is broken up into droplets by an annular array of gas jets, and these droplets then proceed downwards, accelerated by the gas jets to impact onto a substrate. The process is arranged such that the droplets strike the substrate whilst in the semi-solid condition, this provides sufficient liquid fraction to 'stick' the solid fraction together. Deposition continues, gradually building up a spray formed billet of metal on the substrate.



Spray forming offers certain advantages over both conventional ingot metallurgy and more specialized techniques such as powder metallurgy. Firstly, it is a flexible process and can be used to manufacture a wide range of materials, some of which are difficult to produce by other methods, e.g. Al-5wt% Li alloys or Al-SiC, Al-Al2O3 metal matrix composites (MMCs). The atomization of the melt stream into droplets of 10-500 µm diameter, some of which, depending on diameter, cool quickly to the solid and semi-solid state provide a large number of nucleants for the residual liquid fraction of the spray formed material on the billet top surface. The combination of rapid cooling in the spray and the generation of a large population of solid nucleants in the impacting spray leads to a fine equiaxed microstructure, typically in the range 10–100 µm, with low levels and short length scales of internal solute partitioning. These microstructural aspects offer advantages in material strength because of fine grain size, refined distribution of dispersoid and/or secondary precipitate phases, as well as tolerance to impurity ‘tramp’ elements. This fine structure in the ‘as sprayed’ condition means homogenizing heat treatments can often be avoided. Because of the complex solidification path (i.e. the rapid transition from superheated melt to solid, liquid or semi-solid droplet to temperature equilibration at semi-solid billet top and final slow cooling to fully solid) of the spray formed material, extended solubility of alloying elements and the formation of metastable and quasi-crystalline phases has also been reported.

One of the major attractions of spray forming is the potential economic benefit to be gained from reducing the number of process steps between melt and finished product. Spray forming can be used to produce strip, tube, ring, clad bar / roll and cylindrical extrusion feed stock products, in each case with a relatively fine-scale microstructure even in large cross-sections. The benefits of GASF over powder metallurgy accrue from the reduced number of process steps where powder sieving, pressing, de-gassing and handling steps and their attendant safety and contamination issues may be removed.

There are two major disadvantages to the gas atomization spray forming process. The most significant disadvantage is the relatively low process yield with typical losses of ~30%. Losses occur because of overspray (droplets missing the emerging billet), splashing of material from the billet surface, and material 'bouncing' off the semi-solid top surface. Many operators of the spray forming process now use a particle injector system to re-inject the overspray powder, and thus recycle material that would otherwise be lost, or sell the overspray powder as a product in its own right. The second major disadvantage is one of process control. As it is essentially a free-forming process with many interdependent variables, it has proved difficult to predict the shape, porosity or deposition rate for a given alloy. Much of the control is based on operator experience and empirical relationships. It is partly the process complexity and lack of robust process control that has prevented the widespread commercialization of this process. Some developments using feed-back control have proved successful in improving the variations in billet diameter and improving yield in specific systems but these have yet to find widespread implementation.

PROCESS OF SIMULATION:

A) Deformation of the hot cylindrical bar stock:

ALL THE ANALYSIS IS CARRIED OUT IN DEFORM3D V11 MULTIPLE OPERATOR. THE BASIC OUTLINE OR THE IDEA OF THE ANALYSIS IS DONE IN VARIOUS PARTS.

1) Performing a deformation analysis which involves cutting of the cylindrical work piece by the shearing blades
2) Performing the thermal analysis of the shearing blades individually.
3) Performing the thermal analysis of the blades with all the effects considered i.e conduction, convection, radiation and cooling channels.

Deformation analysis of cylindrical work piece

To carry this operation we need to open a new problem in Deform software and open it in MO operator. Assign a new title to the project and file name and save it in the required directory.

When the processing window opens start the operation by choosing 3D Forming option in the explorer tab which is to the extreme right of the window.

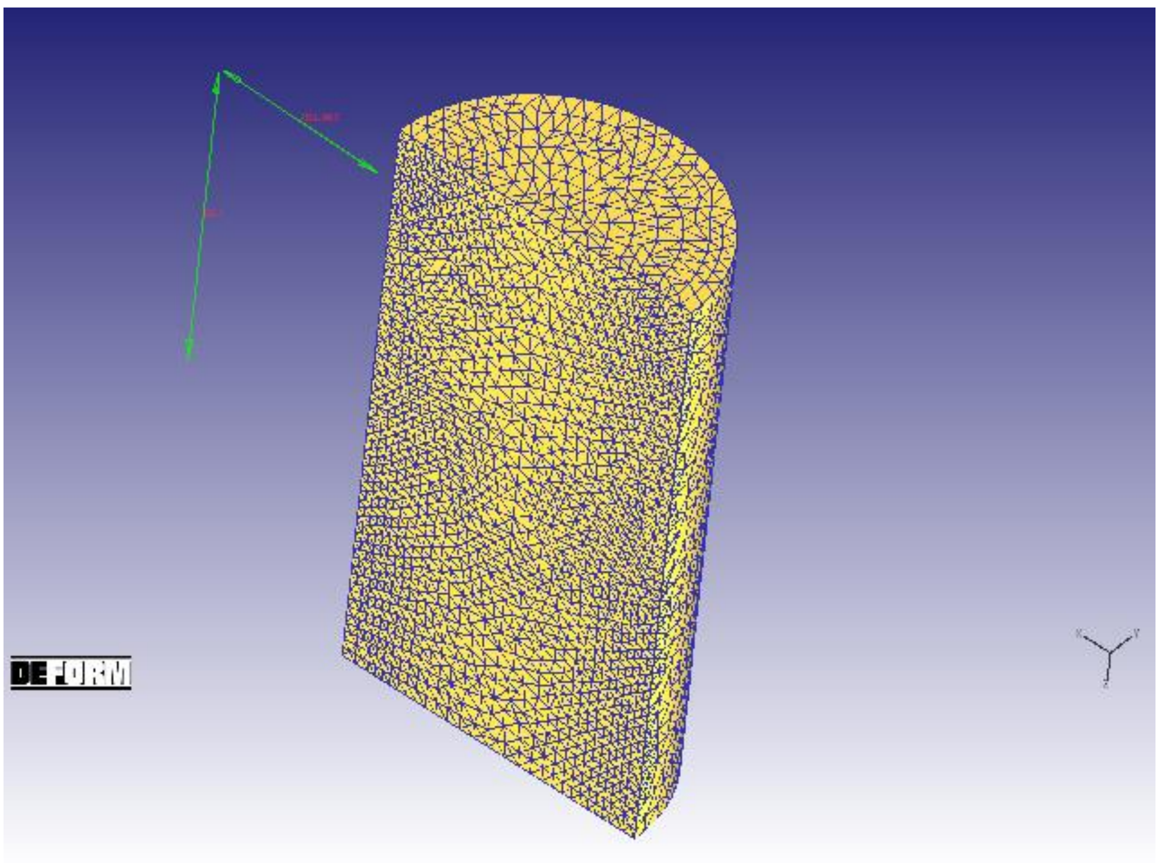
We shall be given four windows in the software which are Graphics window, Operation tree (to the left), Operation editor (bottom), and display window.

Declare four objects in the display window as work piece, top die and bottom die and support die.

WORKPIECE

Set the work piece temperature at 1100C and object type as plastic

Click the geometry option and choose Define primitive to declare the geometry as a cylindrical bar which is symmetrical and generate the mesh with around 30000 elements.



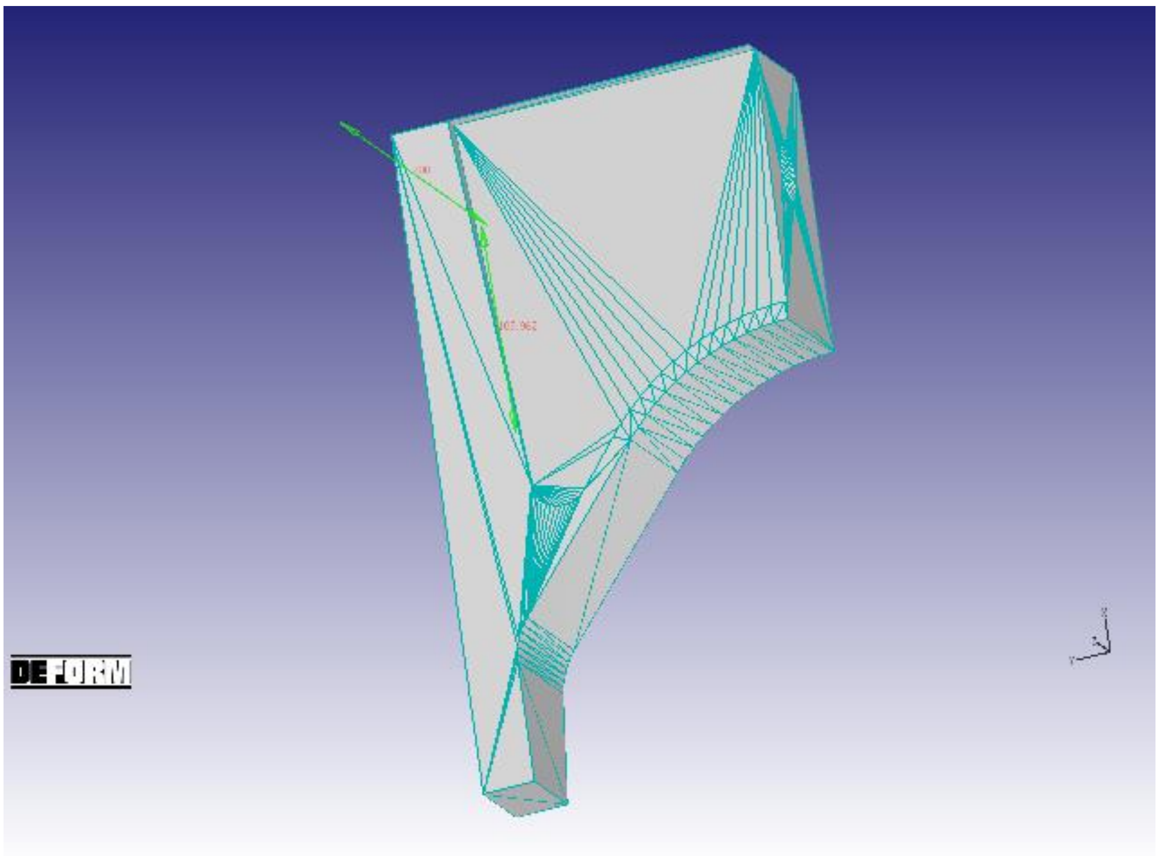
Choose the material of the work piece as DIN-C15 (70-2200F (20-1200C))

Assign the boundary conditions to the work piece by selecting the symmetry option and declaring a symmetry plane by clicking the flat surface to assign the symmetry.

Let the work piece be stationary.

Top Die

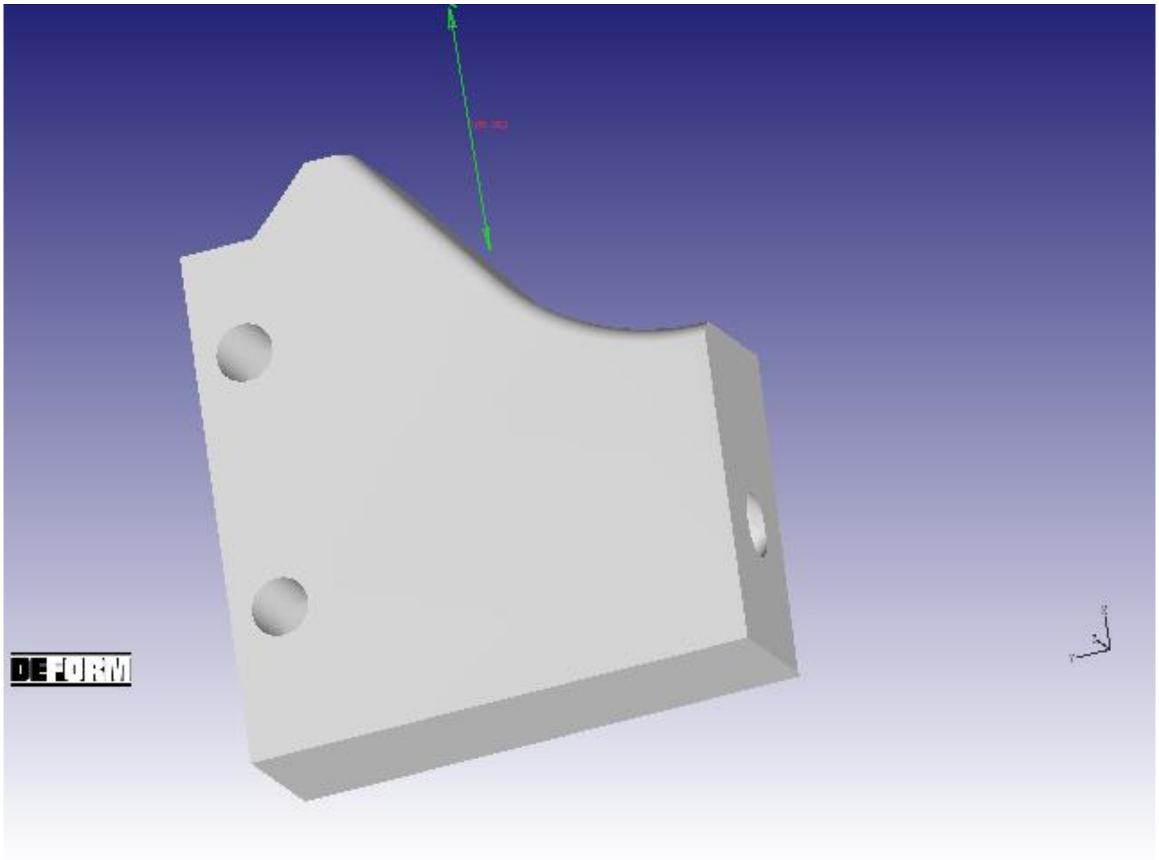
Assign the top die temperature as 20 C and object type as Rigid.



Set the Material of the top die to be AISI D2 and declare the movement of the die in –X direction at 10mm/sec

Bottom Die

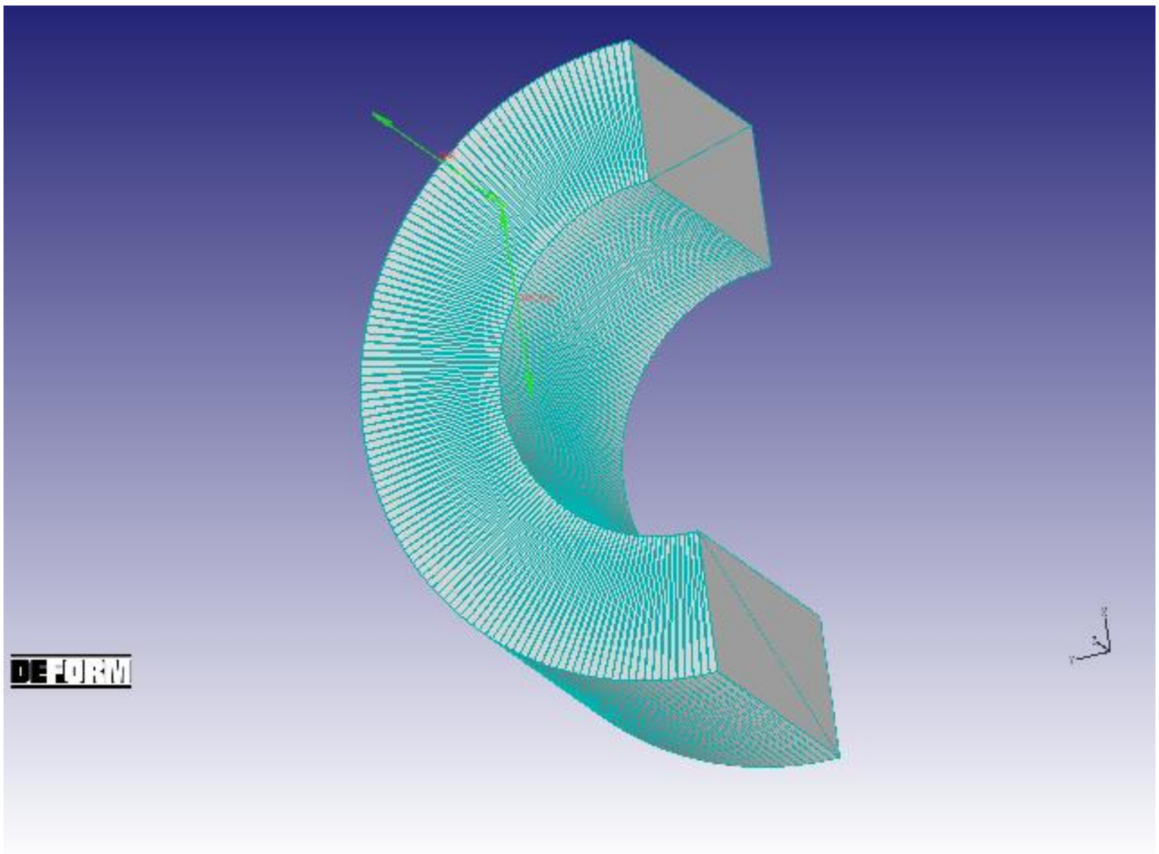
Assign the die temperature as 20 C and object type as Rigid.



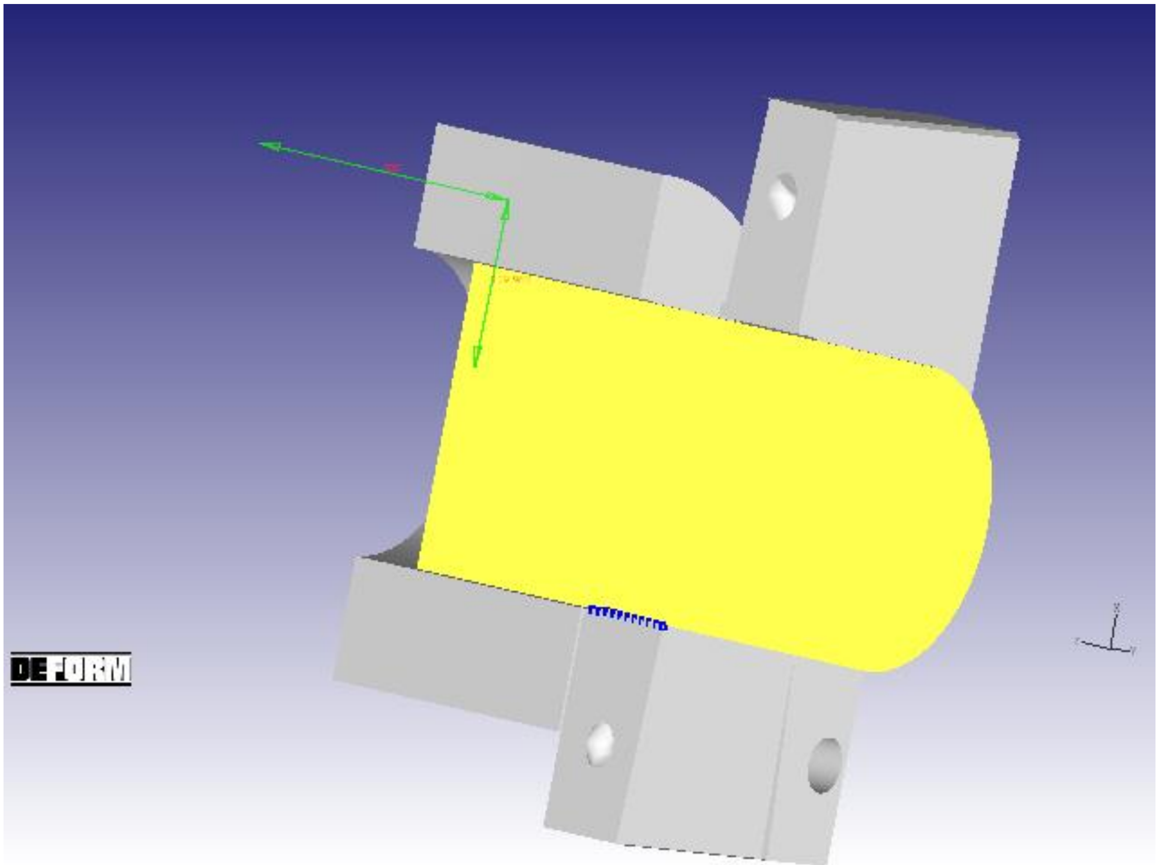
Set the Material of the top die to be AISI D2 and declare the movement of the die as stationary.

Support Die

Assign the die temperature as 20 C and object type as Rigid.



Set the Material of the top die to be AISI D2 and declare the movement of the die as stationary.



Positon the objects to their respective positions using the object positioning option in the controls tab.

Use different operations like drop, drag and revolve options and finally the interference option efficiently to position the objects in their respective positions.

Generate the contact between the work piece and dies using the contact option.

Generate the default master slave options and set the required properties.

In the simulation controls set the maximum number of steps as 100 and step increment to save to be 10 and stopping control to be the maximum displacement of the die as 100mm.

THERMAL ANALYSIS OF LOWER BLADE:

Problems encountered

Actually the simulation must have been carried out with one of the work piece bars sliding on the blade. Due to the inconsistency of contact nodes in all the cycles, there was not enough contact between the bar and the blade which gave very dull results which are inaccurate.

Therefore the simulation is carried out by considering the intermediate position of the sliding work piece bar on the lower blade so that sufficient contact points are generated.

Material Properties:

Choose the material of the work piece as DIN-X12CrNi1613[145-2000F(800-1100C)].

Choose the material of the lower blade as AISI-H-13.

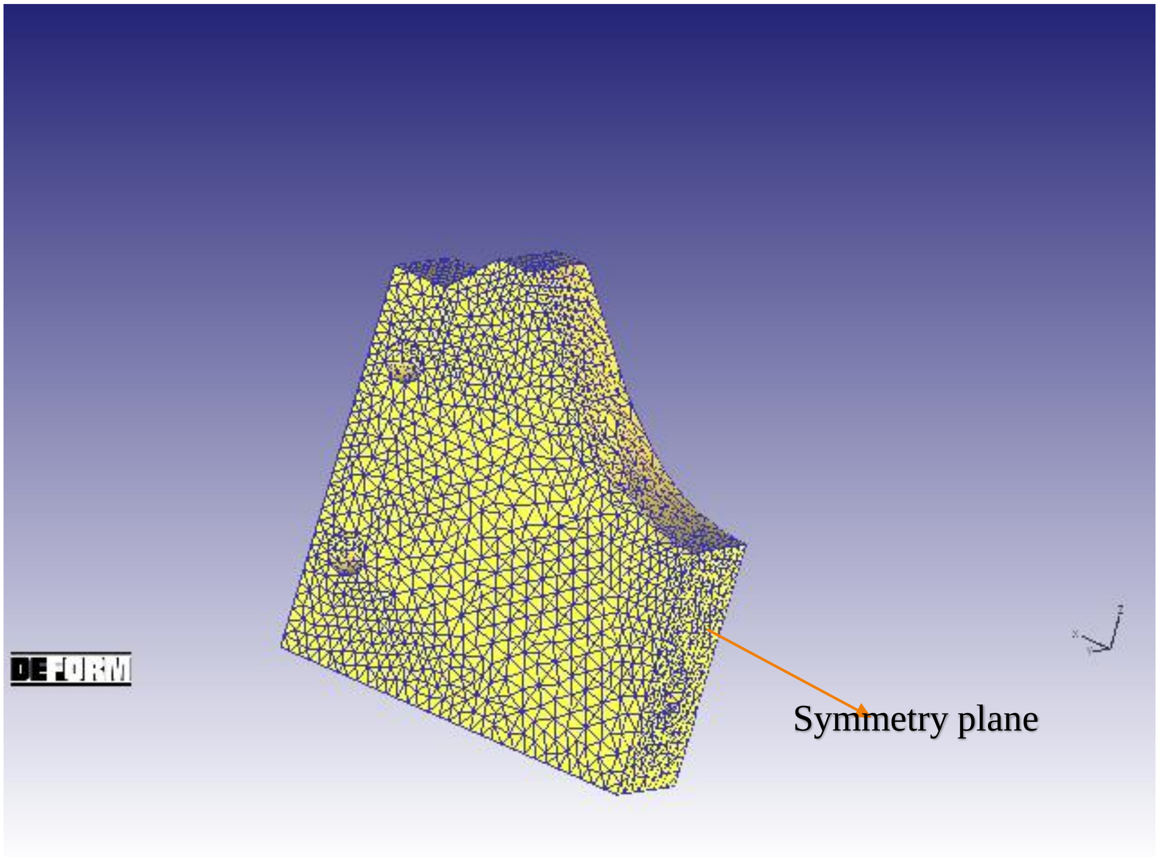
Procedure of Simulation:

To carry this operation we need to open a new problem in Deform software and open it in MO operator. Assign a new title to the project and file name and save it in the required directory.

When the processing window opens start the operation by choosing 3D Forming option in the explorer tab which is to the extreme right of the window.

We shall be given four windows in the software which are Graphics window, Operation tree (to the left), Operation editor (bottom), Display window.

Declare four objects in the display window as work piece, top die and bottom die and heat source.



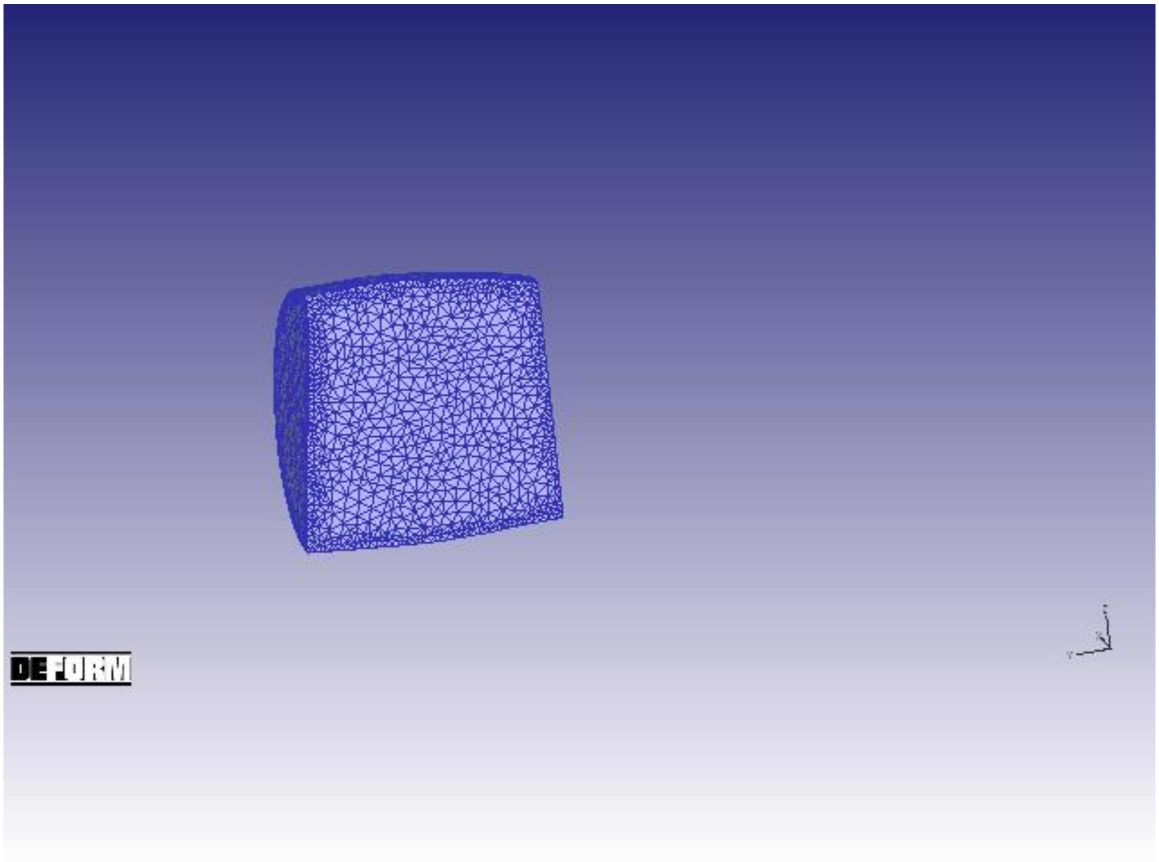
WORKPIECE

- Set the work piece temperature at 20C and object type as plastic.
- Click the geometry option and upload the geometry of the lower blade which is in .STL format and generate the mesh with around 30000 elements.
- Assign the material as AISI-H-13.

Boundary Conditions

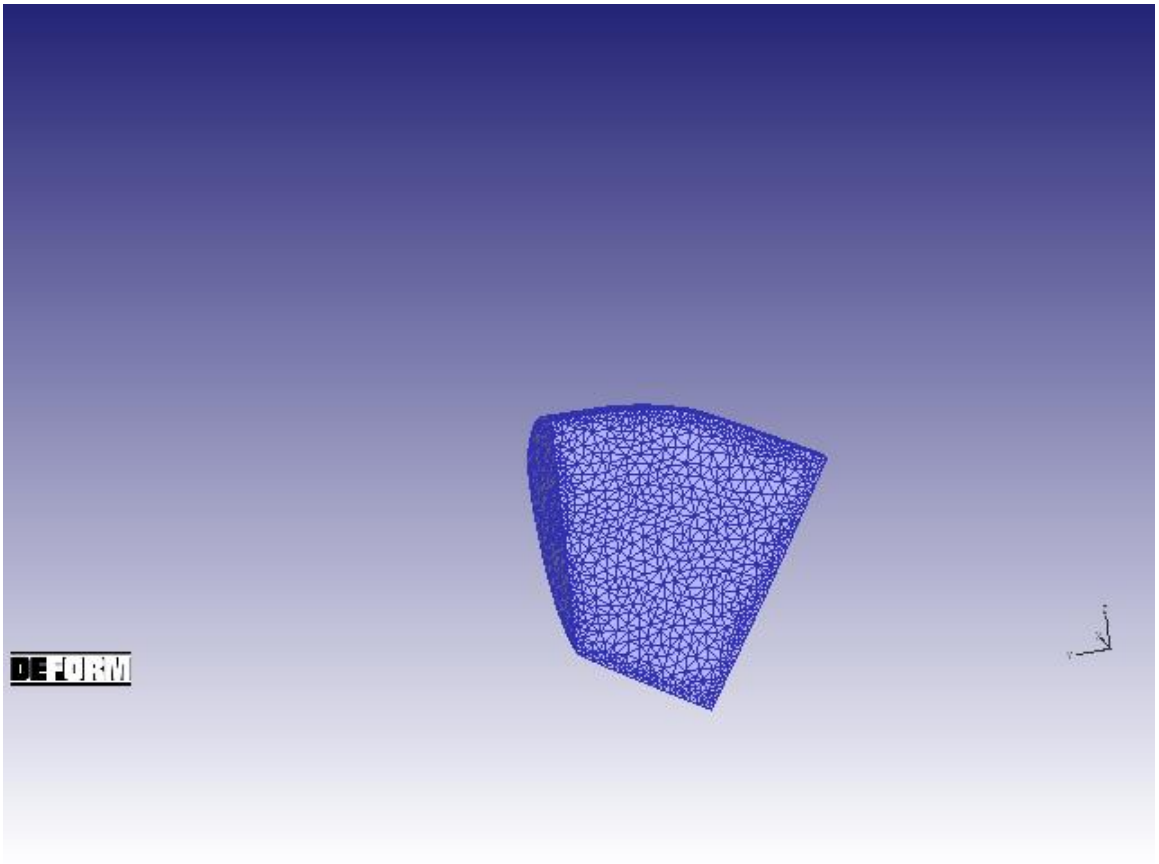
- Declare the symmetry plane so as to have the calculation on the entire lower blade.
- Fix the back surface of the blade which is exactly opposite to the symmetry plane surface in all directions.
- Declare the cooling channel temperature as 50C by selecting the surface where the cooling channel is designed.

- Keep the blade stationary.



Top Die:

- Upload the geometry of the top die which is a part of work piece bar from the saved geometries of the previous deformation simulation.
- Declare the temperature of the bar as 1100C and assign the material as DIN-X12CrNi1613 [145-2000F (800-1100C)].
- Also declare the symmetry plane to have the calculation on whole work piece.
- Assign a force in the negative Z direction with the value of the force as 1N so as to have a good amount of contact nodes with the blade during the entire simulation.



Bottom Die:

- Upload the geometry of the bottom die which is a part of work piece bar from the saved geometries of the previous deformation simulation.
- Declare the temperature of the bar as 1100C and assign the material as DIN-X12CrNi1613 [145-2000F(800-1100C)].
- Also declare the symmetry plane to have the calculation on whole work piece.

Heat source:

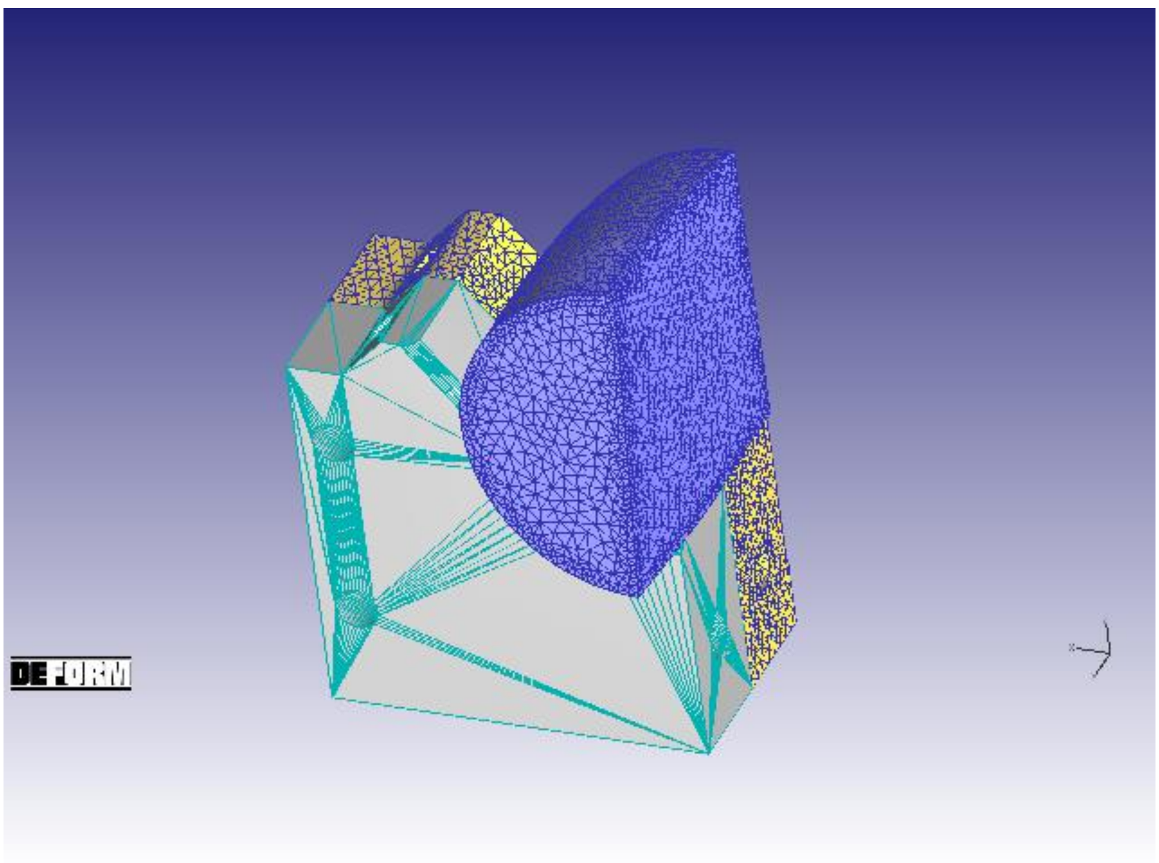
- Upload the geometry of the heat source plate which is similar to the lower die.
- Declare the temperature of the heat source as 600C and assign the material asAISI-H-13.

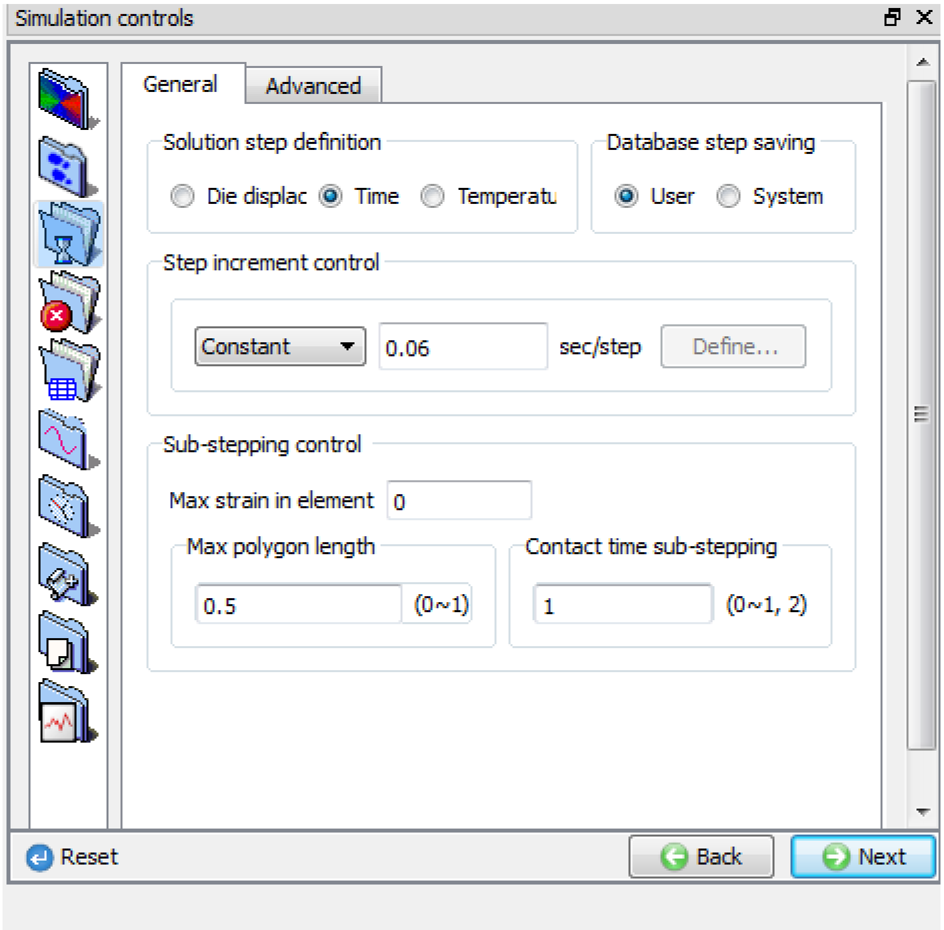
Positon the objects to their respective positions using the object positioning option in the controls tab.

Use different operations like drop, drag and revolve options and finally the interference option efficiently to position the objects in their respective positions.

Generate the contact between the work piece, dies and the heat source plate using the contact option where the tolerance value is set to 1

Generate the default master slave options and set the required properties as cold forming (shear value as 0.12) and heat transfer coefficient as 5N/sec/mm/C.





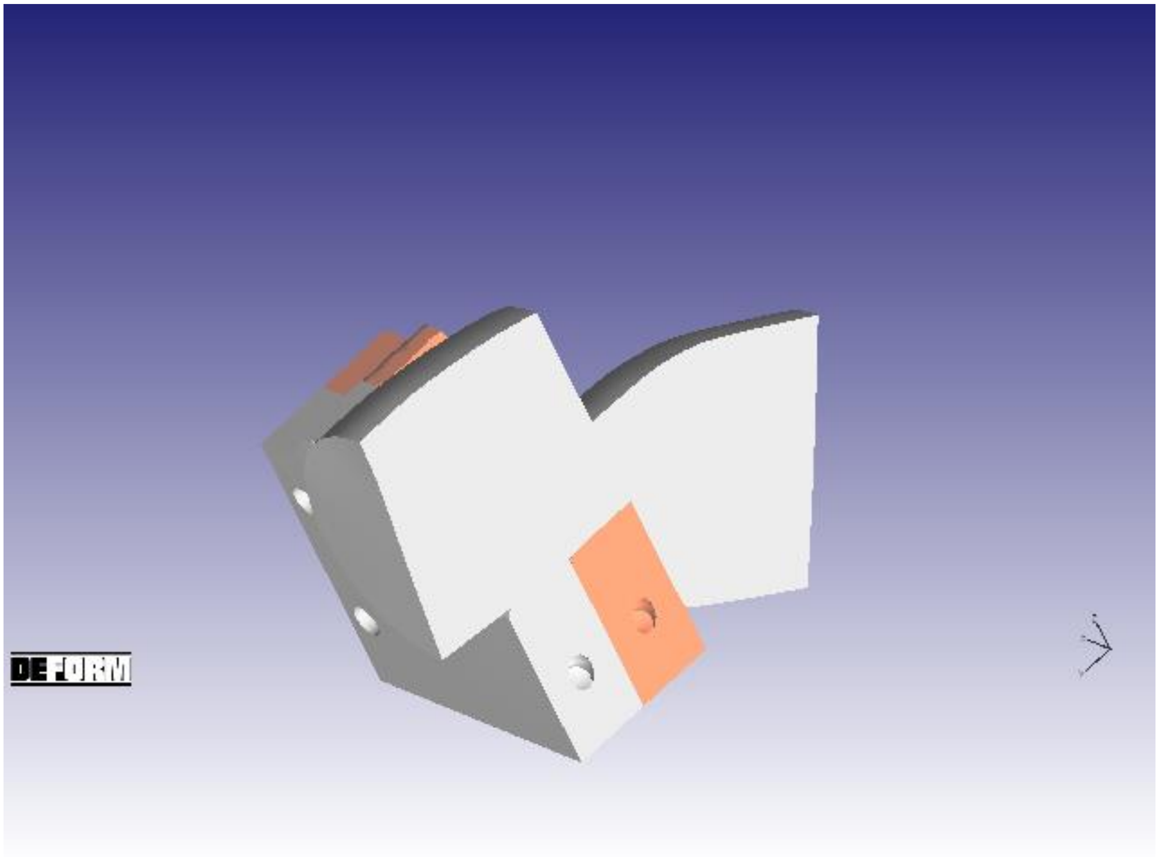
Operation 1:

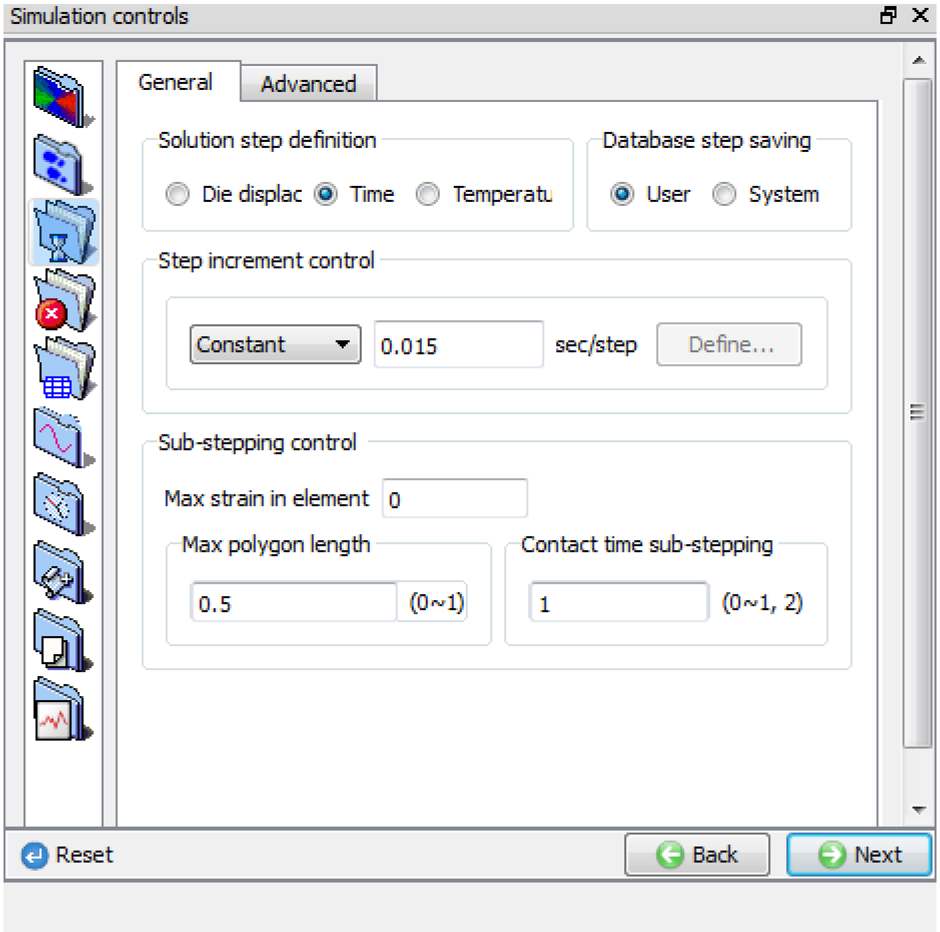
This is the heating operation of lower blade which is done with only still part of the work piece bar and heat source plate.

Simulation controls: Set the no.of simulation steps as 200 and step increment to be saved as 10. Here the primary die is Top die.

Set the solution step definition as time and step increment control as constant which is 0.06.

Check the data and generate the database.


DEFORM

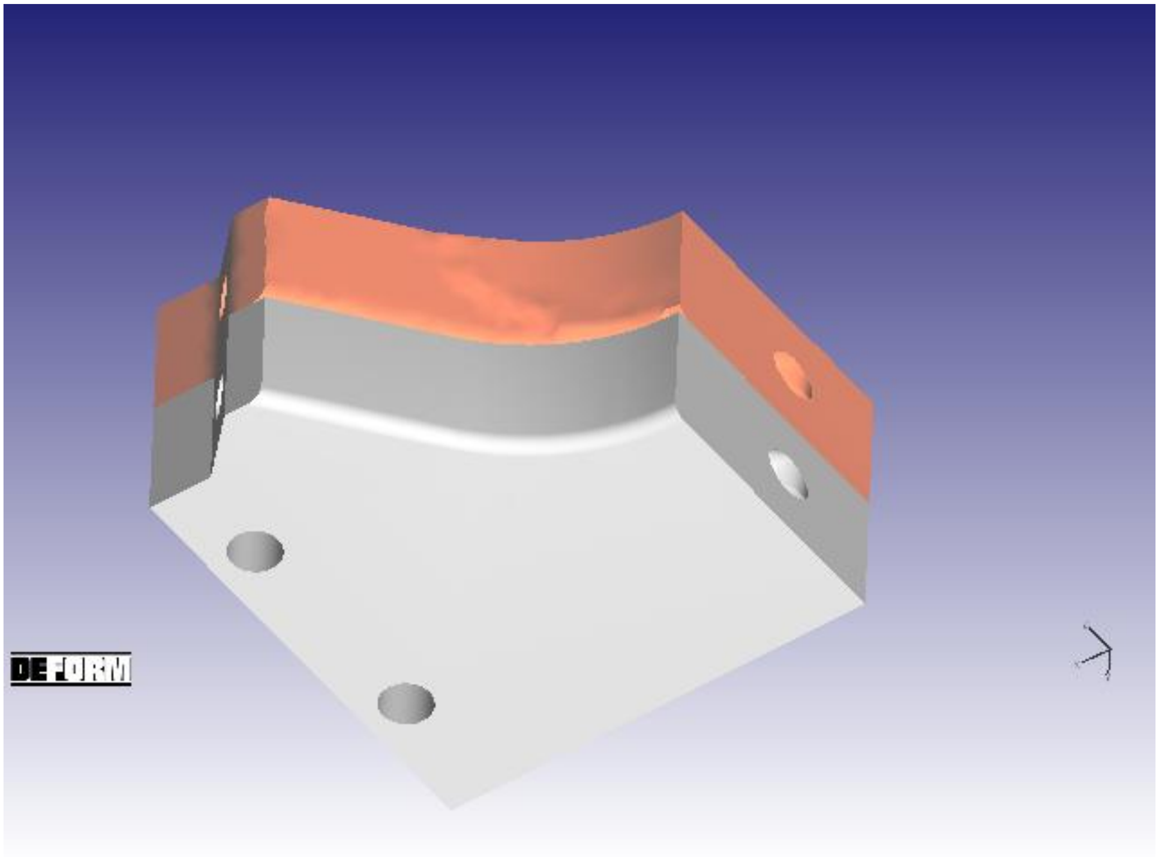


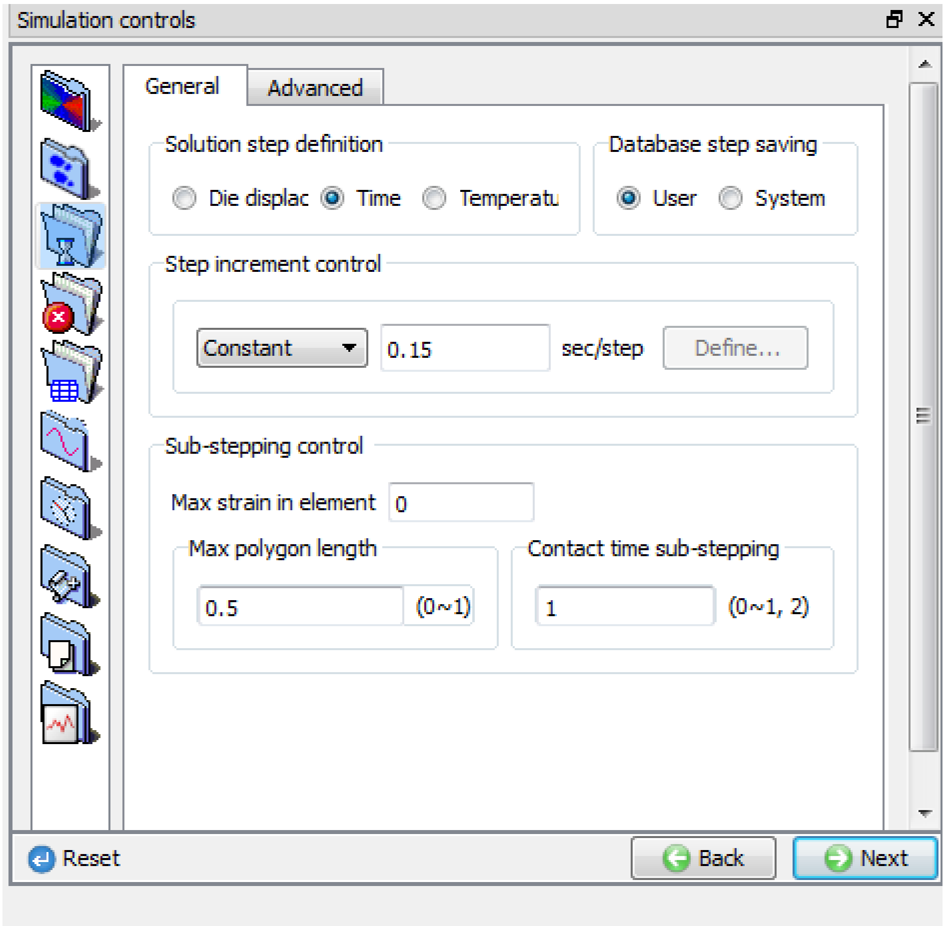
Operation2 :

This is the heating operation of lower blade which is done with still part of the work piece bar, heat source plate and other part of the workpiece bar.

Simulation controls: Set the no.of simulation steps as 200 and step increment to be saved as 10. Here the primary die is Top die.

Set the solution step definition as time and step increment control as constant which is 0.015.


DEFORM



<u>Operation3 :</u>

This is the cooling operation of lower blade which is done with the heat source plate.

<u>Simulation controls:</u> Set the no.of simulation steps as 200 and step increment to be saved as 10. Here the primary die is Top die.

Set the solution step definition as time and step increment control as constant which is 0.15.

Right click on the second operation and click on add cycle option. Drag the operation3 into the cycle and declare the no.of cycles as 10.

THERMAL ANALYSIS OF UPPER BLADE:

Problems encountered

Actually the simulation must have been carried out with one of the work piece bars sliding on the blade. Due to the inconsistency of contact nodes in all the cycles, there was not enough contact between the bar and the blade which gave very dull results which are inaccurate.

Therefore the simulation is carried out by considering the intermediate position of the sliding work piece bar on the Upper blade so that sufficient contact points are generated.

Material Properties:

Choose the material of the work piece as DIN-X12CrNi1613[145-2000F(800-1100C)].

Choose the material of the Upper blade as AISI-H-13.

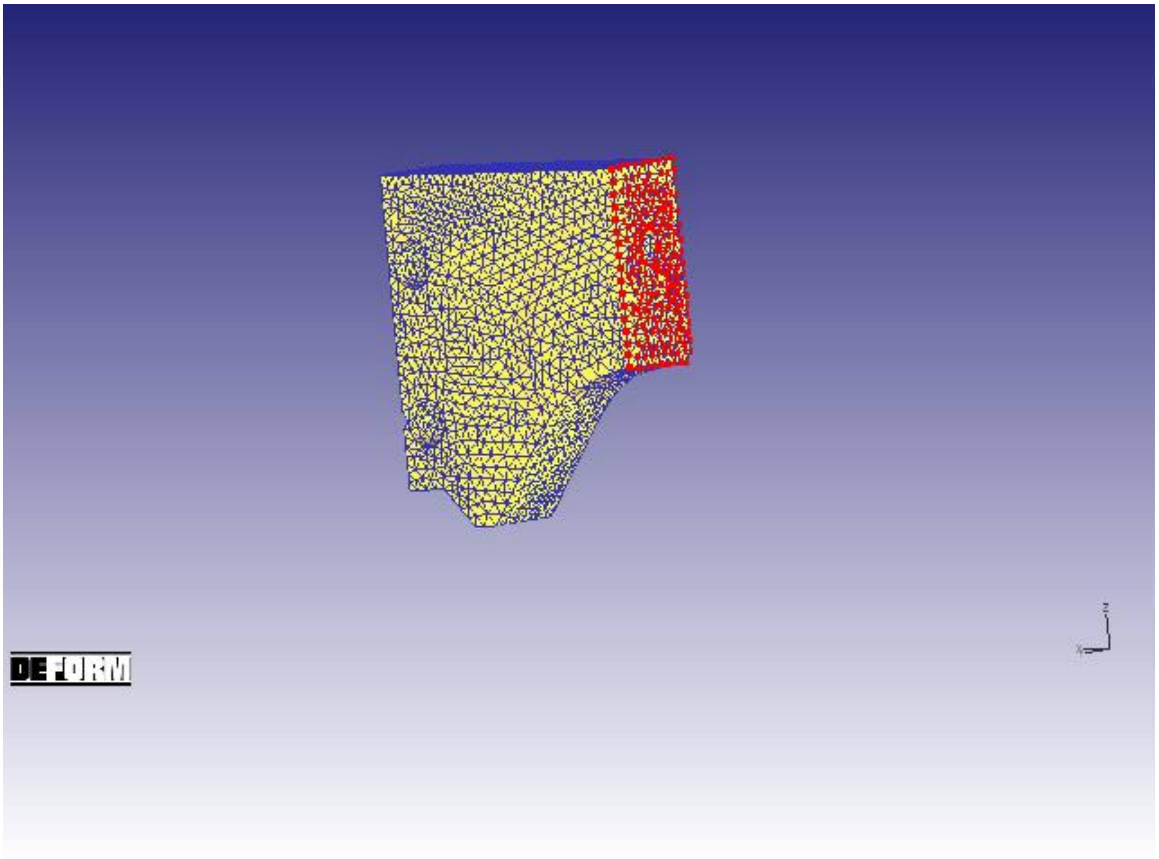
Procedure of Simulation:

To carry this operation we need to open a new problem in Deform software and open it in MO operator. Assign a new title to the project and file name and save it in the required directory.

When the processing window opens start the operation by choosing 3D Forming option in the explorer tab which is to the extreme right of the window.

We shall be given four windows in the software which are Graphics window, Operation tree (to the left), Operation editor (bottom), Display window.

Declare three objects in the display window as work piece, top die and bottom die.



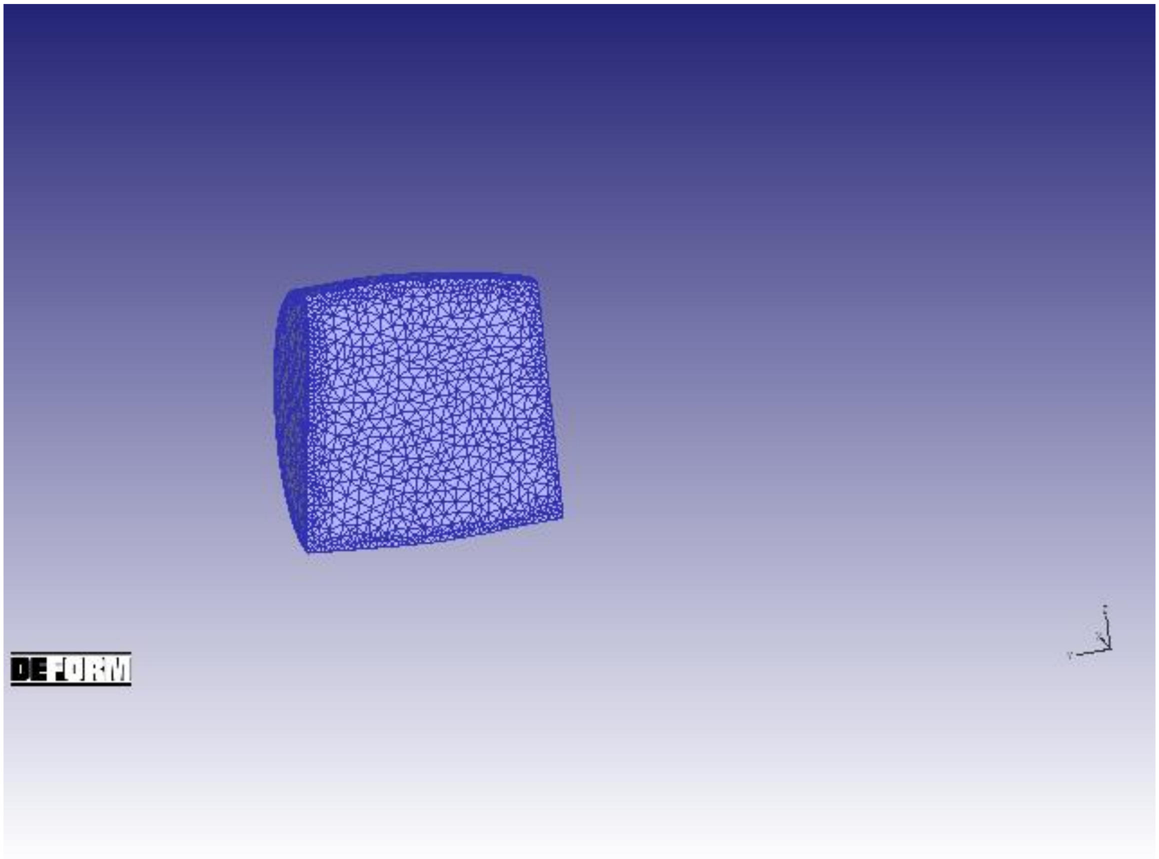
WORKPIECE

- Set the work piece temperature at 20C and object type as plastic.
- Click the geometry option and upload the geometry of the Upper blade which is in .STL format and generate the mesh with around 30000 elements.
- Assign the material as AISI-H-13.

Boundary Conditions

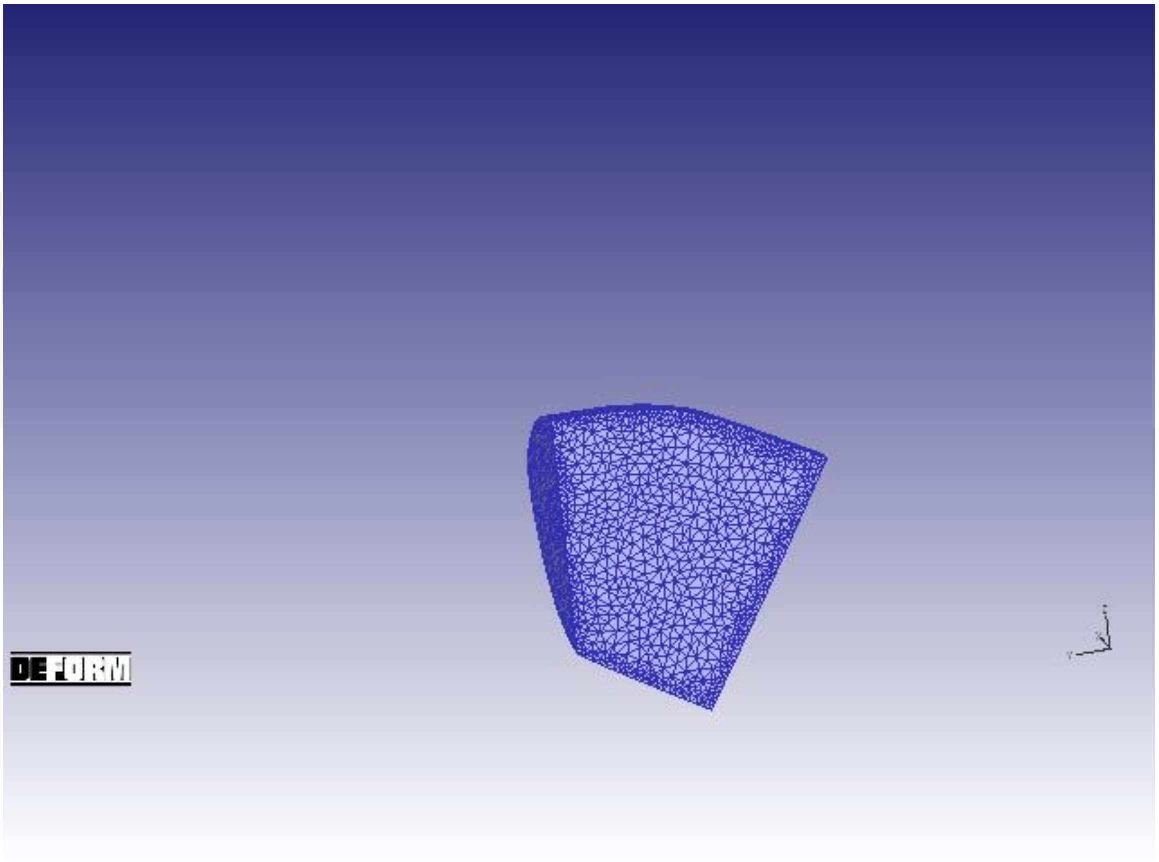
- Declare the symmetry plane so as to have the calculation on the entire Upper blade.
- Fix the back surface of the blade which is exactly opposite to the symmetry plane surface in all directions.
- Declare the cooling channel temperature as 100C by selecting the surface where the cooling channel is designed.

- Keep the blade stationary.



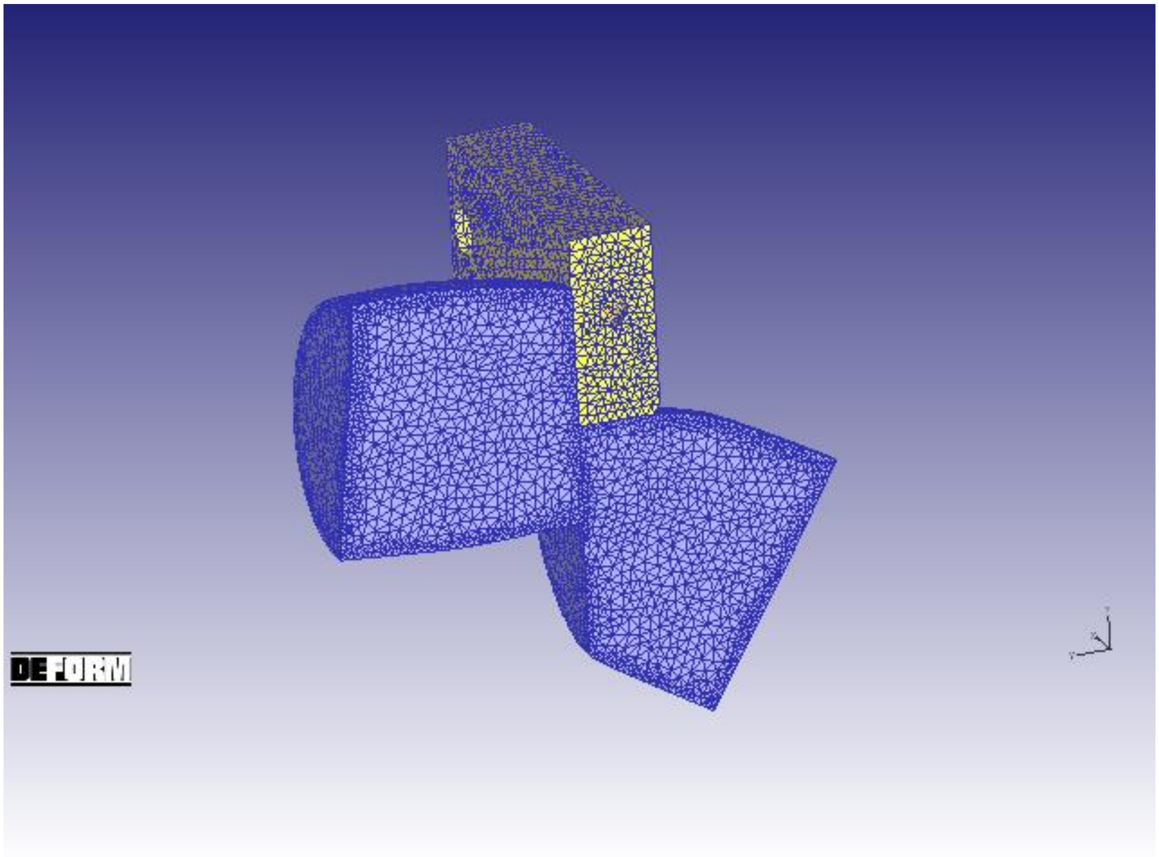
Top Die:

- Upload the geometry of the top die which is a part of work piece bar from the saved geometries of the previous deformation simulation.
- Declare the temperature of the bar as 1100C and assign the material as DIN-X12CrNi1613 [145-2000F(800-1100C)].
- Also declare the symmetry plane to have the calculation on whole workpiece.



Bottom Die:

- Upload the geometry of the bottom die which is a part of work piece bar from the saved geometries of the previous deformation simulation.
- Declare the temperature of the bar as 1100C and assign the material as DIN-X12CrNi1613 [145-2000F(800-1100C)].
- Also declare the symmetry plane to have the calculation on whole work piece.

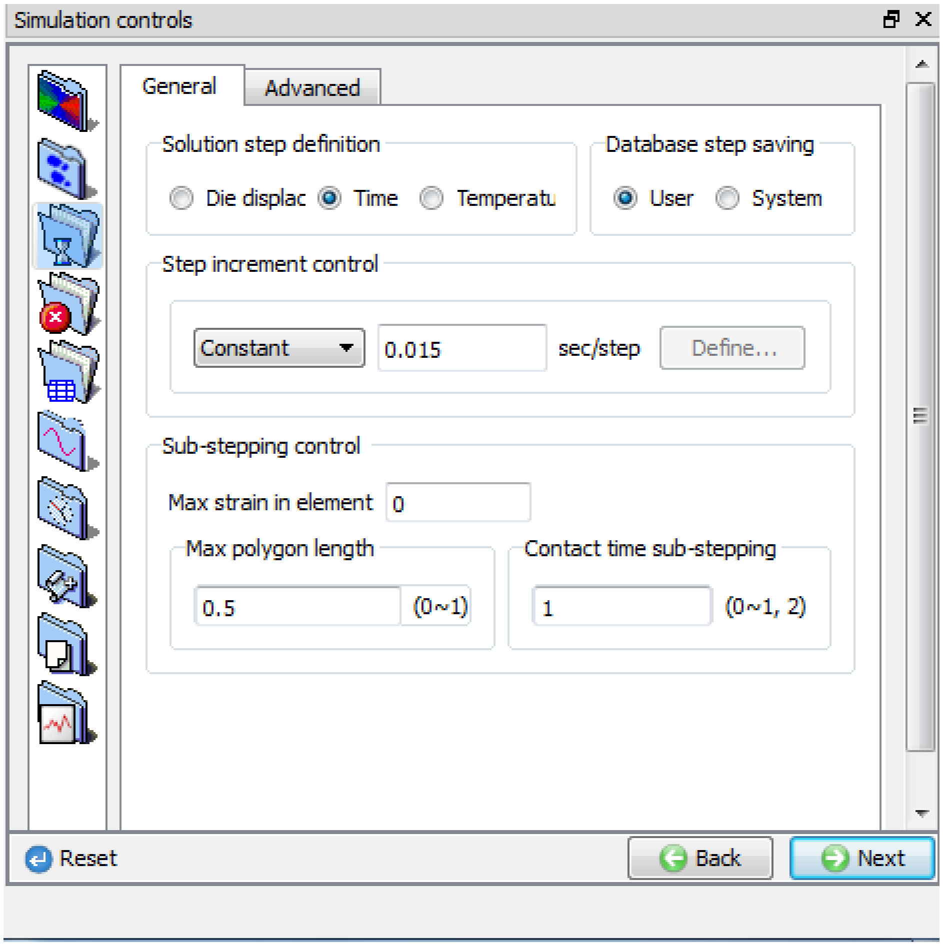


Positon the objects to their respective positions using the object positioning option in the controls tab.

Use different operations like drop, drag and revolve options and finally the interference option efficiently to position the objects in their respective positions.

Generate the contact between the work piece, dies and the heat source plate using the contact option where the tolerance value is set to 1

Generate the default master slave options and set the required properties as cold forming (shear value as 0.12) and heat transfer coefficient as 5N/sec/mm/C.



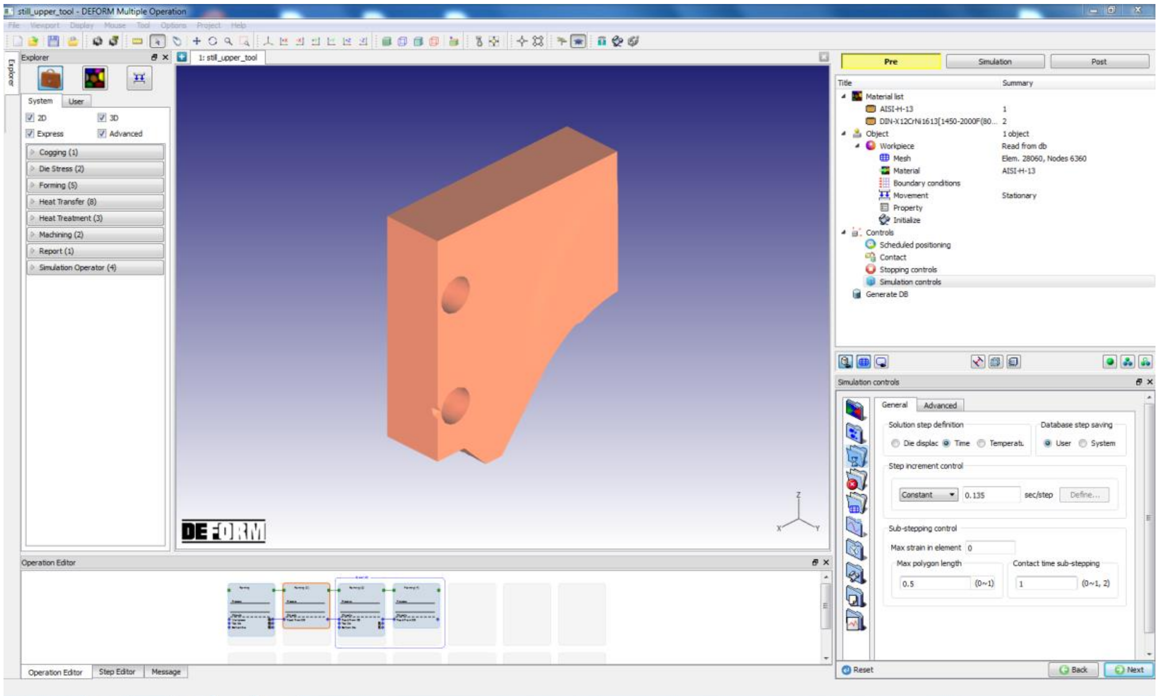
<u>Operation 1:</u>

This is the heating operation of Upper blade which is done with work piece bars.

<u>Simulation controls:</u> Set the no.of simulation steps as 200 and step increment to be saved as 10. Here the primary die is Top die.

Set the solution step definition as time and step increment control as constant which is 0.015.

Check the data and generate the database.



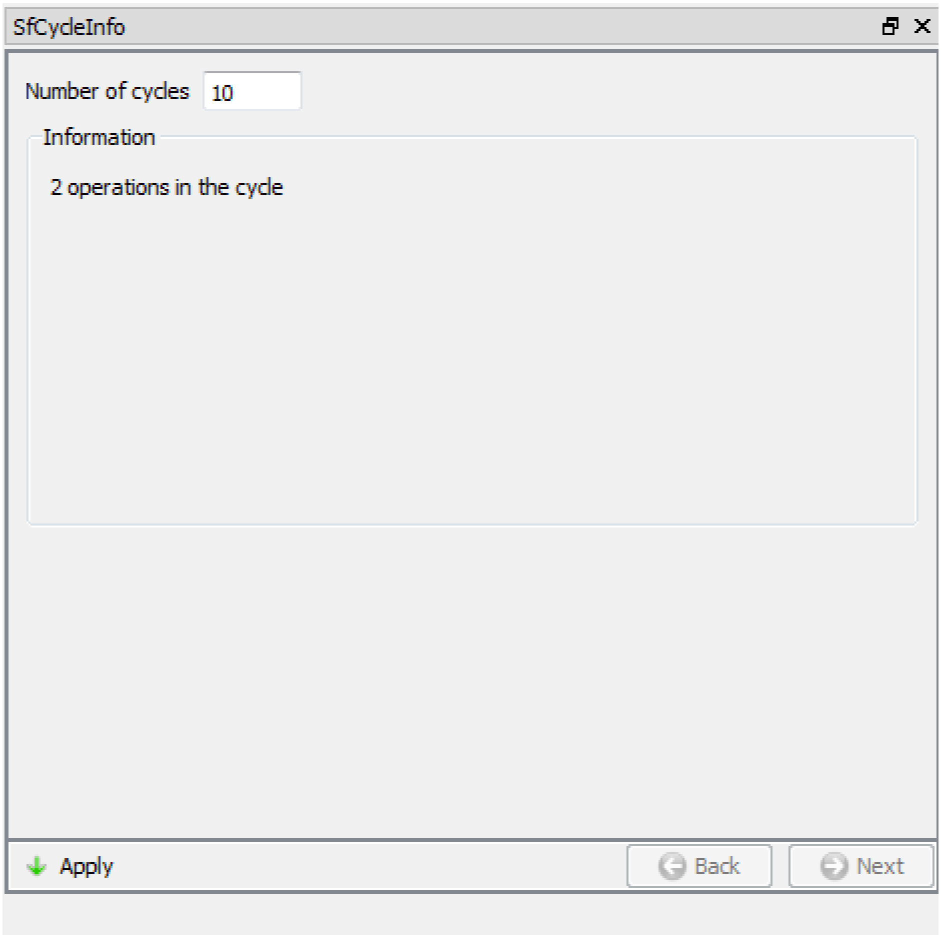
Operation2 :

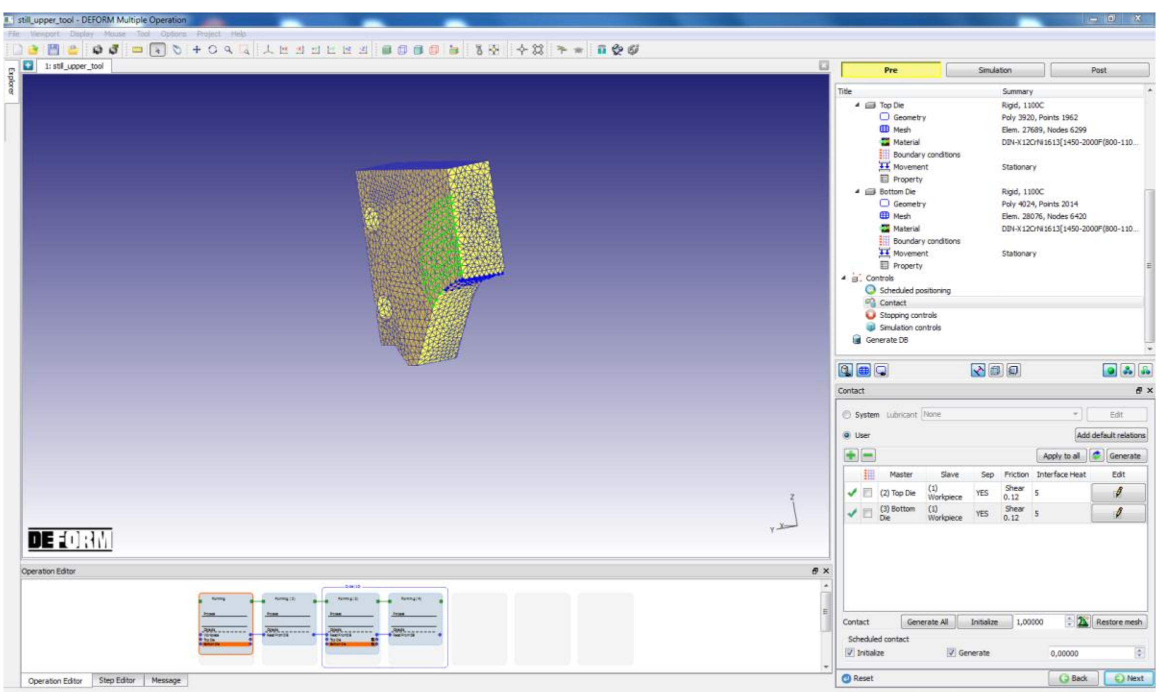
This is the cooling operation of Upper blade.

Simulation controls: Set the no.of simulation steps as 200 and step increment to be saved as 10. Here the primary die is Top die.

Set the solution step definition as time and step increment control as constant which is 0.15.

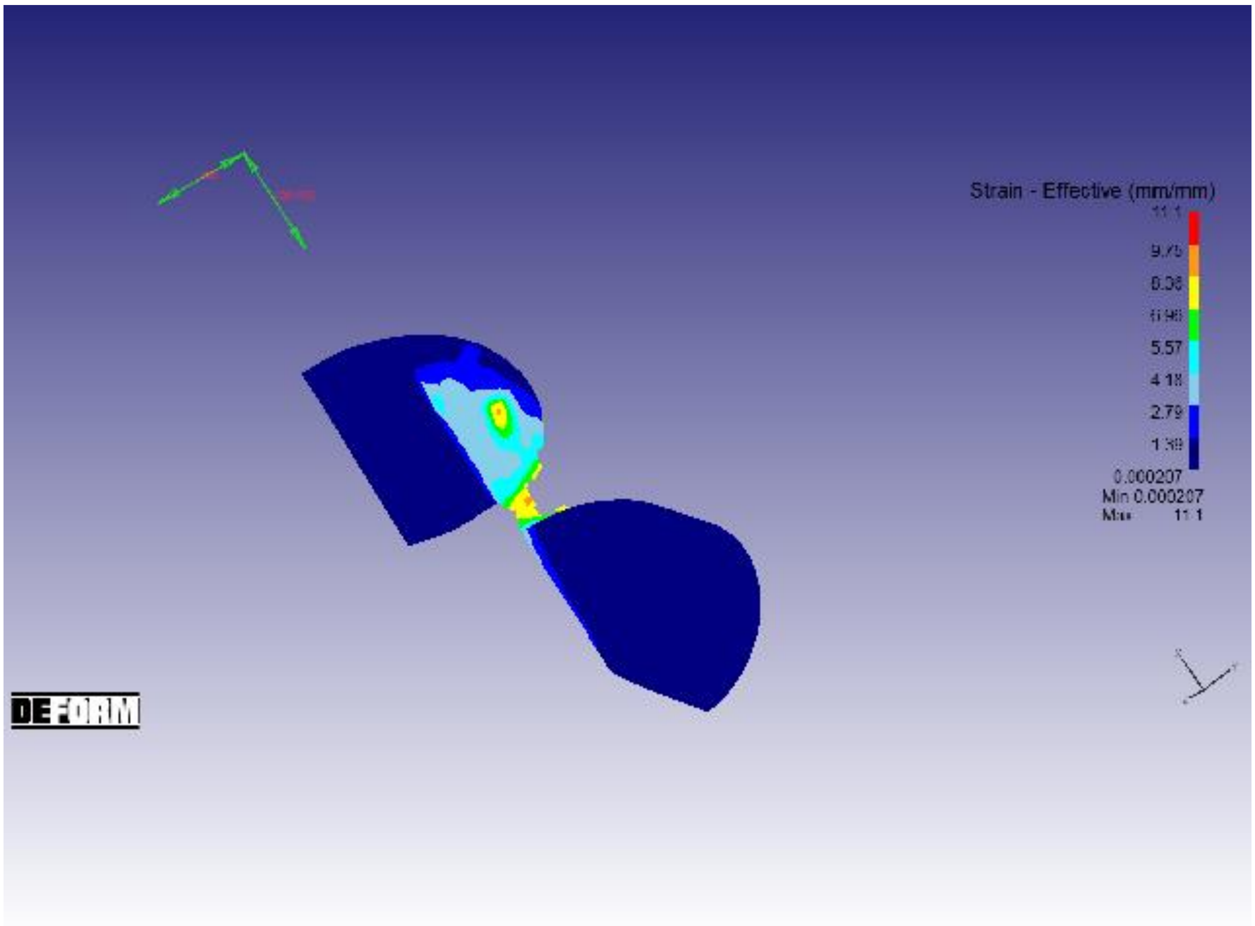
Right click on the second operation and click on add cycle option. Drag the operation3 into the cycle and declare the no.of cycles as 10.


SfCycleInfo
Number of cycles
10
Information
2 operations in the cycle
Apply
Back
Next


Pre
Simulation
Post
DEFORM

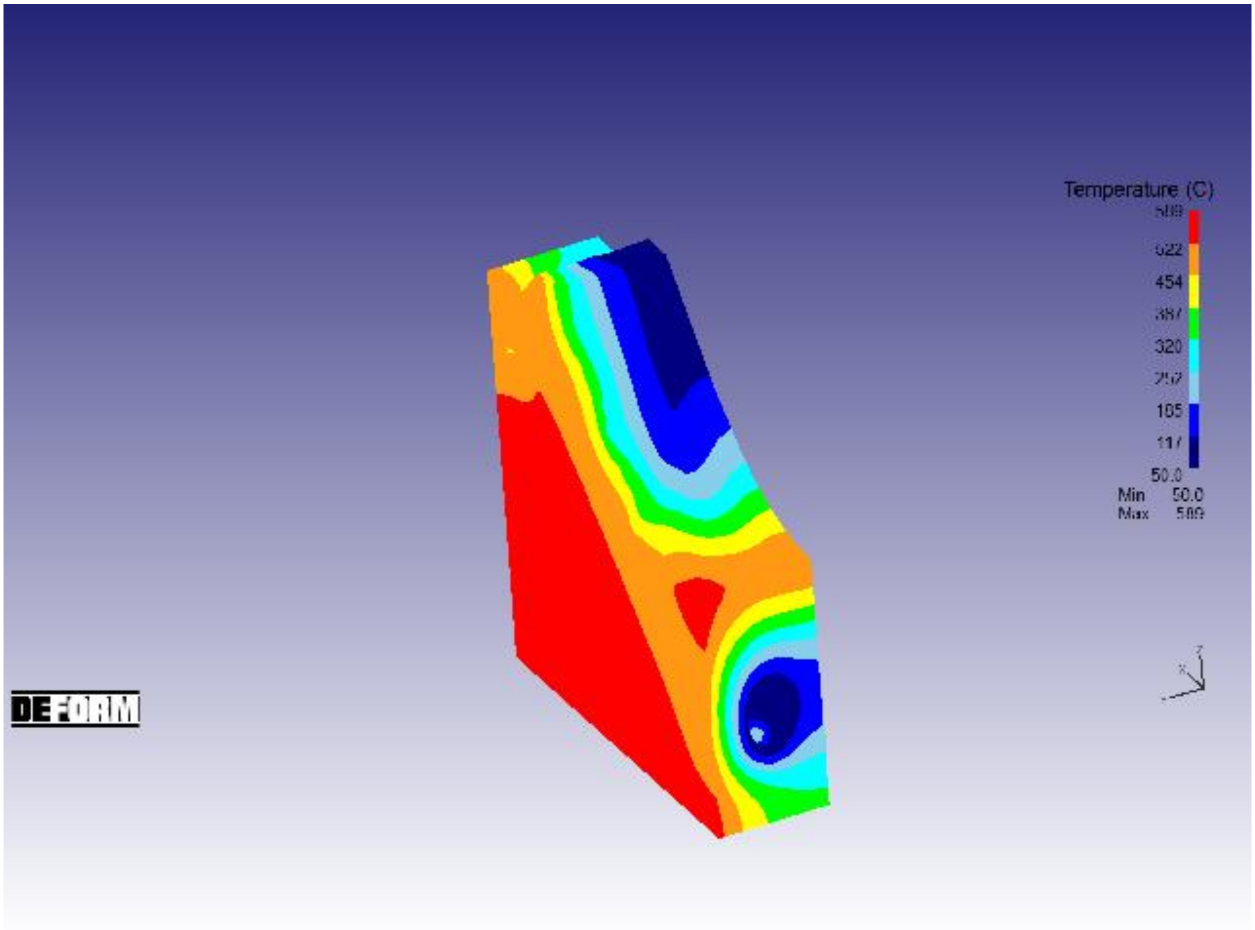
RESULTS

The entire simulation is carried out in three stages. At first the cylindrical bar stock is taken in red hot condition and subjected to deformation by using the rigid blades. This deformed bar is taken to the further stages in which it is used as a heat source for the shear blades. This gives credence to the entire machining process of sliding action and shearing. The deformed cylindrical bar at the end of the simulation is shown below in the figure

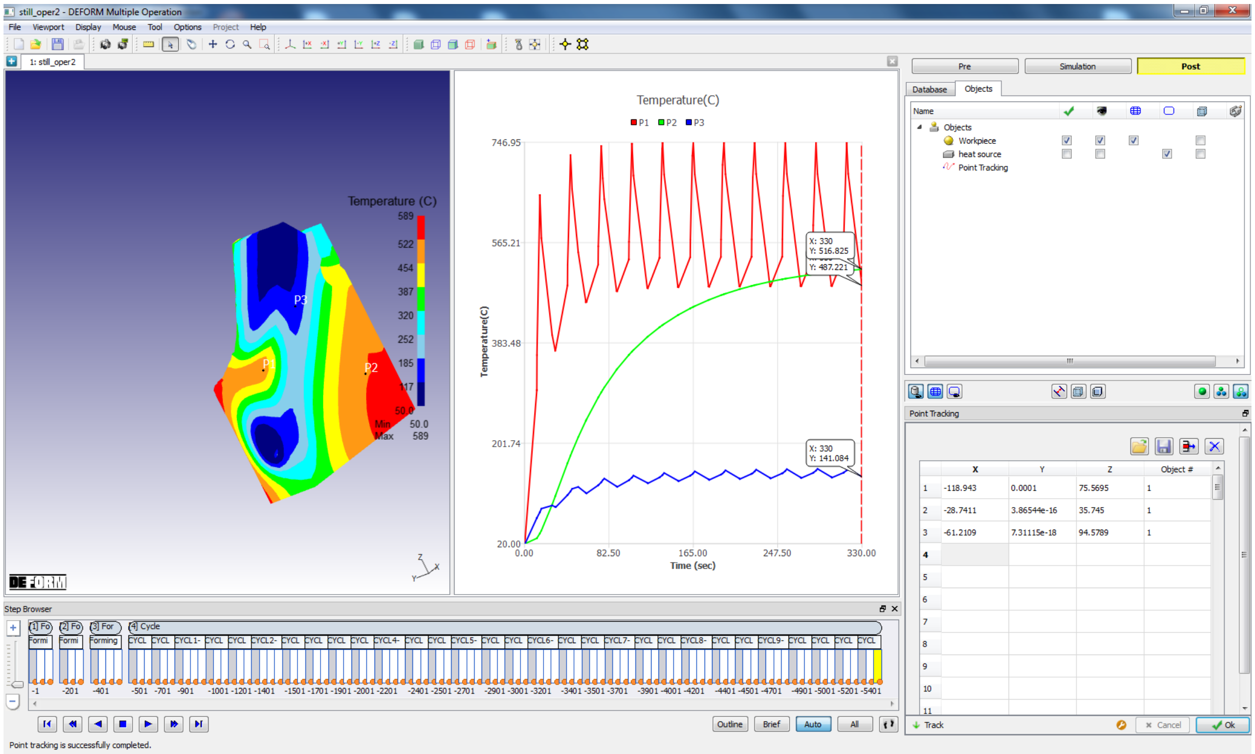


From the figure it can be inferred that the bar is not completely deformed in to two slices instead there is a small continuity of the material which can hinder the further simulations. Hence the above bar is sliced in order to have a plain finished surface. This will make ensure that the contact between the blades and the bar remain intact. By doing this more accurate results can be obtained. At the end of the simulation, it has been noted that the average force which has been imposed on the bar by the blades during machining as 176KN.

The second part of the simulation is done to the lower blade. In this simulation the deformed bar stock is kept in contact with the lower blade.

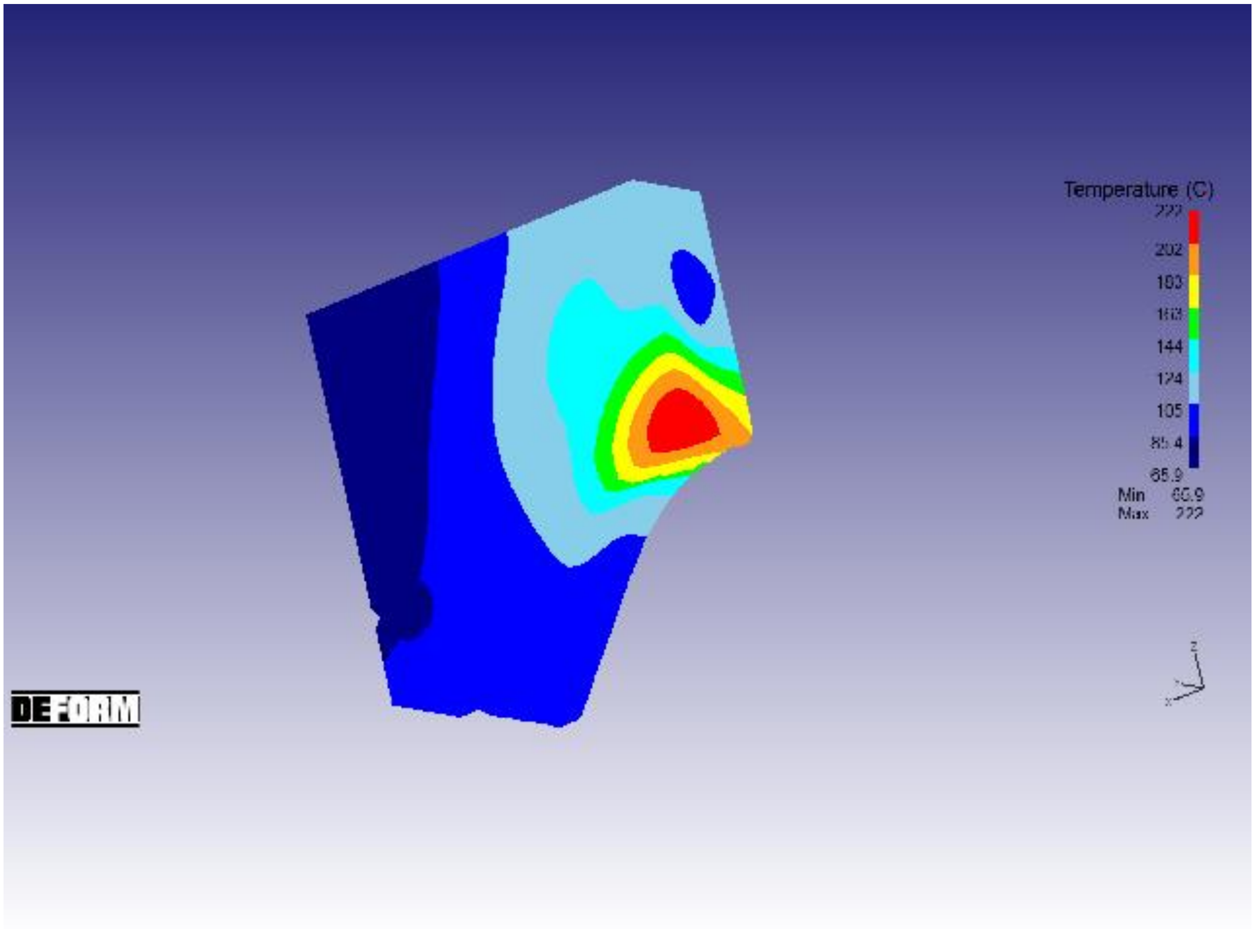


The above figure depicts the temperature distribution of the lower blade at the end of ten operations. The maximum temperature can be seen at the central art of the tool which accounts to 589C. This is the stagnation temperature of the blade. The cooling channel reduces the maximum temperature of the lower blade to some extent form 898C to 589C.

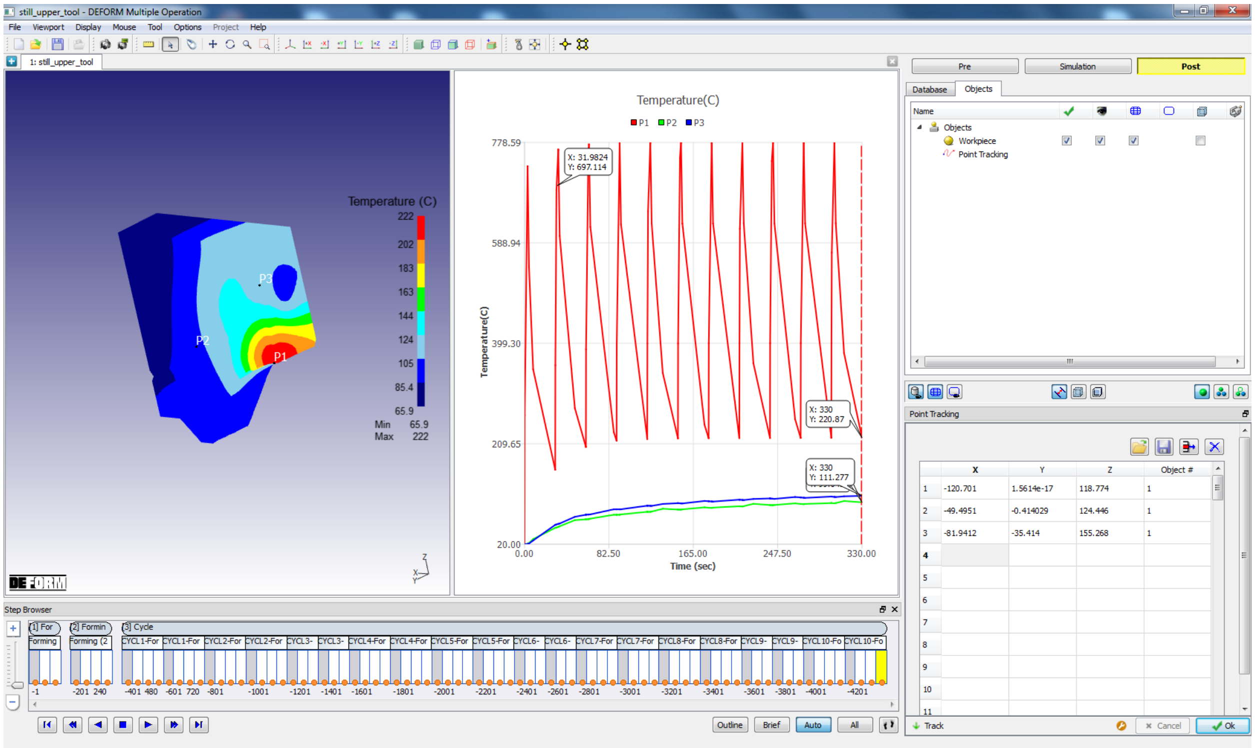


The above figure depicts the variation of temperature for selected points in the lower blade. All the three variations in the temperature reach to a stagnation level at the end of ten cycles.

Similar process has been carried out with the upper blade.

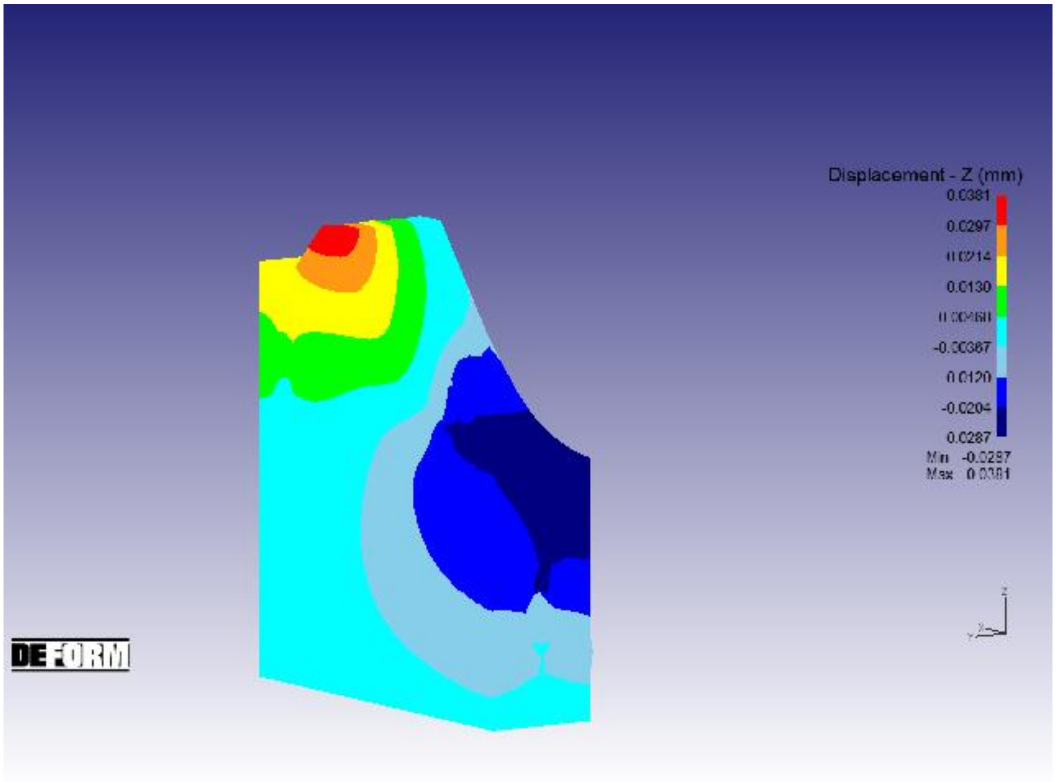


The above figure depicts the temperature distribution of the upper blade at the end of ten operations. The maximum temperature can be seen at the central art of the tool which accounts to 222C. This is the stagnation temperature of the blade. The cooling channel reduces the maximum temperature of the lower blade to some extent form 338C to 222C.

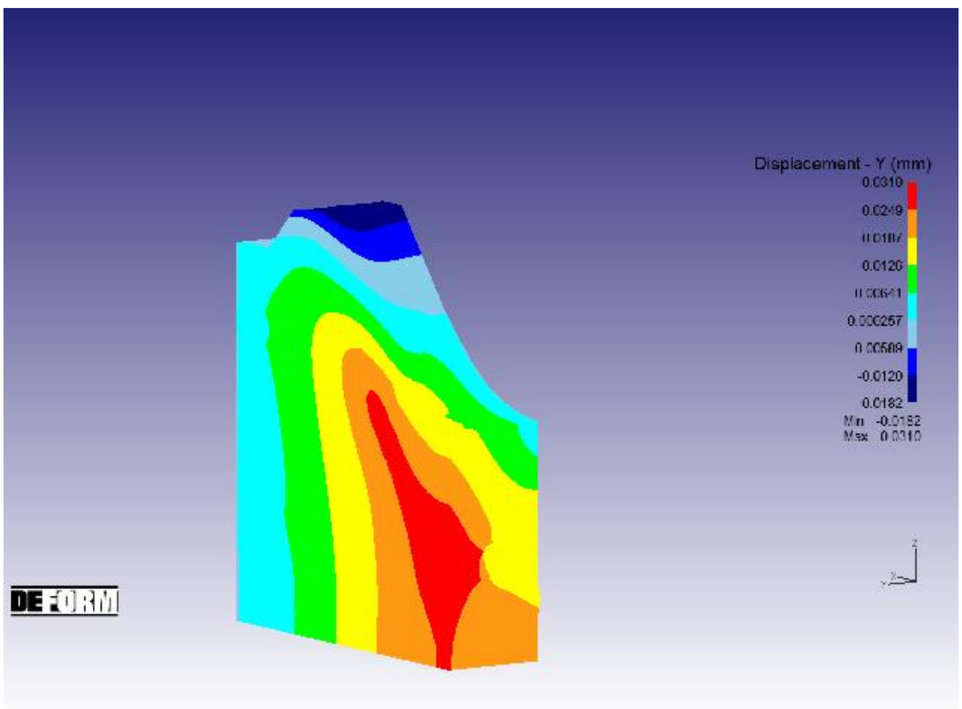


The above figure depicts the variation of temperature for selected points in the lower blade. All the three variations in the temperature reach to a stagnation level at the end of ten cycles.

Mechanical loading is also considered for which the blades are hinged at particular positions getting close to the machine setup fixture. The results were interesting because of the displacement characteristics shown by the blades. Below figure depicts the displacement properties.



The above figure depicts the displacement characteristics of the lower blade in Z direction.



The above figure depicts the displacement characteristics of the lower blade in Y direction.

CONCLUSIONS

1. The goal of this project is to determine the temperature distribution of the shear blades and to carry out the thermos mechanical cyclic loading on the shear blades using Deform 3D.
2. While deforming the cylindrical bar stock, it has been observed the bar undergoes in complete deformation which does not result in good finish of the billets.
3. The major strain changes occur in the central part of the cylindrical bar stock.
4. The upper blade takes the less heat from the bar stock when compared to the lower blade and this tends to abnormal dislocations in the end billet.
5. It has been observed that the present cooling channels are inevitable and are required to be improved.

REFERENCES:

1. **Rüdiger Rentsch, Olaf Grohmann(2010)**, Application of a composite hot shearing tool manufactured by co-spray forming.
2. Akira Ohtomo and Atsushi Tsukazaki(2005), Pulsed laser deposition of thin films.
3. www.deform .com
4. http://www.trumpf-laser.com/en/solutions/applications/laser-welding/deposition-welding.html.
5. http://www.lpwtechnology.com/technical-information/laser-metal-deposition/
6. http://www.rpm-innovations.com/laser_deposition_technology
7. http://www.advantagefabricatedmetals.com/shearing-process.html
8. http://thelibraryofmanufacturing.com/forming_basics.html