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DESIGN AND ANALYSIS OF INJECTION MOULD FOR MINERAL WATER BOTTLE CAP

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ABSTRACT:

Injection moulding is the most important process in the manufacturing of plastic parts. It is done by forcing melted plastic in to a mould cavity until it cools and forms a specific plastic shape. Plastic injection moulding is very useful when the plastic parts that need to be produced are too complex or expensive to do by machine. With plastic injection moulding, many parts can be made simultaneously (using the same mould).

The plastics used are the thermo-plastic (hdpe) as these materials soften when heated and re-harden when cooled. No chemical changes take place when the material is heated or cooled, the change being entirely physical. For this reason, the softening and re-hardening cycle can be repeated any number of times.

In this work, stress analysis of this cap cavity plate under the pressure 40 n/mm^2 is considered, in addition to this thermal analysis is carried out at injection temperature 220^{0}c and mould temperature 20^{0}c.

Introduction

The injection moulding process:

The injection moulding process is the process of forcing molten plastic into a mould cavity. Once the plastic has cooled, the part can be ejected. This is often used in mass-production and prototyping. It is a relatively new way to manufacture parts. The first injection moulding machines were built in the 1930's.

There are six major steps in the injection moulding process:

1. Clamping: an injection moulding machine consists of three basic parts; the mould plus the clamping and injection units. The clamping unit is what holds the mould under pressure during the injection and cooling. Basically, it holds the two halves of the injection mould together.
2. Injection: during the injection phase, plastic material, usually in the form of pellets, are loaded into a hopper on top of the injection unit. The pellets feed into the cylinder where they are heated until they reach molten form. Within the heating cylinder there is a motorized screw that mixes the molten pellets and forces them to end of the cylinder. Once enough material has accumulated in front of the screw, the injection process begins. The molten plastic is inserted into the mould through a spruce, while the pressure and speed are controlled by the screw.
3. Dwelling: the dwelling phase consists of a pause in the injection process. The molten plastic has been injected into the mould and the pressure is applied to make sure all of the mould cavities are filled.
4. Cooling: the plastic is allowed to cool to its solid form within the mould.
5. Mould opening: the clamping unit is opened, which separates the two halves of the mould.
6. Ejection: an ejecting rod and plate eject the finished piece from the mould. The un-used spruces and runners can be recycled for use again in future moulds.

1.2 Advantages of injection moulding:

- High production rates
- High tolerances are repeatable
- Wide range of materials can be used
- Low labour costs
- Minimal scrap losses
- Little need to finish parts after moulding

1.3 Disadvantages of injection moulding:

- Expensive equipment investment
- Running costs may be high
- Parts must be designed with moulding consideration

1.4. Problem specification:

Cap is extracted from injection moulding. The injection exerts high pressure and under high temperature. The design of the die cavity for the cap is critical since cavity has to withstand the high temperatures and pressures. In this work the die cavity for the cap is analyzed by using a finite element package ansys 10. So the deformation of the cap cavity plate stress caused are found out and analysed.

2. Methodology:

The procedures to be followed for methodical mould design.

1. Selection of the injection moulding machine: it is essential to design the mould with the machine requirements and capacity of the machine. Before mould design is commenced, it is necessary to determine the press capacity that will be required for successful operation. The essential considerations are shot capacity, plasticising rate, clamping force, injection pressure.
2. Number of cavities: the number of cavities in injection moulding machine is determined in the most cases by the machine performance, but sometimes by the moulding shape, mould locking force or the output required in a given period.
3. Layouts of cavities in multi-impression moulds: this requires considerable care to achieve the best result. During layout of cavities the consideration to be borne in mind includes
   - Optimum disposition of cavities to achieve minimum overall size of the moulds.
   - Attainment of minimum length of runners to cavities.
   - Correct layout of cavities to obtain balanced clamping.
4. Design of feed system: there are some considerations to be kept in mind while designing a feed system for a particular mould.
   - The shape and cross-section of the runner.
   - The size of the runner and
   - The runner layout.
5. Design of gate: the gate should be located such that it can be easily removed without damaging the part and also after de-gating only a small witness mark will remain on the component. the optimum size of the gate will depend upon number of factors including

   The flow characteristics of the plastic material.
   - The mould wall thickness.
   - The moulding temperature.
   - Volume of moulding etc.
6. Design of cooling system: all the injection moulding are generally provided with cooling in order to solidify the hot plastic material which is injected inside the cavity during moulding process. cooling is accomplished by a continuous circulation of chilled water, air or oil flowing through the channel which are drilled in various portion of the mould in order to control the mould temperature.
7. Design of ejection system: all the thermo-plastic materials contract as they solidify which means that the moulding will shrink on to the core which forms on it. this shrinkage makes the moulding difficult to remove. ejection should be a positive action and ejector pin also placed in a position that the ejection marks will not be seen on the product when it is in normal use.
8. Venting: venting is of special importance with multiple gating. Vents must be placed at all points where the plastic fronts coming from different

gates meet to prevent air entrapment, and bad welding of plastics. Venting may also affect injection speed.

It is not being true to say that there are probably as many design for injection moulds as there are different plastic products. Each product to be moulded has its peculiar problems, which must be considered when designing the moulds.

Plastic, a unique class of material comes into existence, the virtue of their superior properties & cost performance balance over to conventional materials like wood, ceramics and metals.

PROPERTIES OF HDPE:

PHYSICAL PROPERTIES

DENSITY (KG/MM^3 : 0.95E^{-9}

SPECIFIC HEAT (J/KG-K) : 472.7

THERMAL CONDUCTIVITY (W/MM-K): 0.0424

MECHANICAL PROPERTIES

POISONS RATIO: 0.46

COEFFICIENT OF FRICTION: 0 .29

TENSILE STRENGTH (MPA): 15-40

MODULUS OF ELASTICITY (GPA): 0.86

ELONGATION : 100

ULTIMATE TENSILE STRENGTH (MPA): 30

Material P20 Type Pre-Hardened Mould Steel:

P20-type, pre-hardened steel that can be used for all plastic molding. It is the highest quality P20-type mold steel currently available, and is superior to all other P20-type mold steels in terms of machining, stability, and welding.

- Exceptionally clean steel with uniform microstructure – no pin holes, inclusions or hard spots.
- 30-33 hrc hardness.
- Uniform hardness throughout, even in heavy sections.
- 75% tougher than typical chrome-moly steels.
- Patented chemistry suppresses weld cracking and hardness elevation in the heat affected zone, eliminating the need for pre-heating and post-heating in most welding situations.
- Machines 30-50% faster than any other p20-type steel.
- Never needs stress relieving, even after heavy machining.

3.6 PROPERTIES OF P20 STEEL:

MECHANICAL PROPERTIES

TENSILE STRENGTH (MPA) : 834

MODULUS OF ELASTICITY (GPA) : 186

ELONGATION (%): 20

ULTIMATE TENSILE STRENGTH (MPA) : 961

THERMAL CONDUCTIVITY (W/MM-K): 0.0424

ANALYSIS OF INJECTION MOULD

Finite element method has become one of the most widely used techniques, for analyzing mechanical loading characteristics in modern engineering components. Traditional analysis techniques can only be satisfactorily applied to a range of conventional component shapes and specific loading conditions. Unfortunately, the majority of engineering loading situations are not simple and straight forward therefore the traditional techniques often need to be modified and compromised to suit situations for which they were not intend. The uncertainty thus created, commonly leads to the designer applying excessively high factor of safety to the mechanical loads and so to over design components by specifying either unnecessarily bulky cross section or high quality materials, inevitably the cost of the product is adversely affected.

Finite element method is one of the numerical methods that process certain characteristics that take advantage of special facilities, offered by the high speed computers. In particular the finite element method can be systematically programmed to accommodate such complex and difficult problems as non-homogeneous materials, non linear stress strain behaviour and complicated boundary conditions.

FEA PROCEDURE:

The basic steps involved in the fea are:

- Modelling, descretization of the given domain using finite elements of different types, shapes and orders.
- Approximation of field variables over each element domain.
- Element matrix generation.
- Imposition of boundary and constraint conditions.
- Solution of global matrix equations.
- Post processing of the result.

SOLID92ELEMENT DESCRIPTION:

- 3-D 10-Node Tetrahedral Structural Solid92 has a quadratic displacement behavior and is well suited to model irregular meshes (such as produced from various CAD/CAM systems).
- The element is defined by ten nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. The element also has plasticity, creep, swelling, stress stiffening, large deflection, and large strain capabilities.

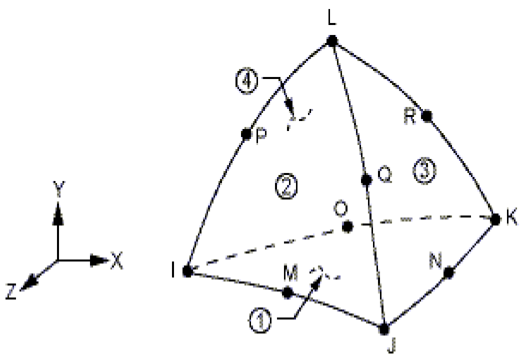

Fig-4.1: **SOLID92 Geometry**

SOLID92 Input Data:
The geometry, node locations, and the coordinate system for this element are shown in Fig-4.1: solid92 Geometry.

Beside the nodes, the element input data includes the orthotropic material properties. Orthotropic material directions correspond to the element coordinate directions. The element coordinate system orientation is as described in Systems. Element loads are described in Node and Element Loads. Pressures may be input as surface loads on the element faces as shown by the circled numbers on Fig-4.1: solid92 Geometry. Positive pressures act into the element. Temperatures and Fluencies may be input as element body loads at the nodes. The node I temperature T (I) defaults to TUNIF. If all other temperatures are unspecified, they default to T (I). If all corner node temperatures are specified, each mid side node temperature defaults to the average temperature of its adjacent corner nodes. For any other input temperature pattern, unspecified temperatures default to TUNIF. Similar defaults occurs for fluency except that zero is used instead of TUNIF.

4.4.1 SOLID92 INPUT SUMMARY:

NODES - I, J, K, L, M, N, O, P, Q, R

DEGREES OF FREEDOM - UX, UY, UZ

REAL CONSTANTS- None

MATERIAL PROPERTIES - EX, EY, EZ, ALPX, ALPY, ALPZ (or CTEX, CTEY, CTEZ *or* THSX, THSY, THSZ), PRXY, PRYZ, PRXZ (or NUXY, NUYZ, NUXZ), DENS, GXY, GYZ, GXZ, DAMP

SURFACE LOADS- PRESSURES -Face 1 (J-I-K), face 2 (I-J-L), face 3 (J-K-L), face 4 (K-I-L)

BODY LOADS - TEMPERATURES -T(I), T(J), T(K), T(L), T(M), T(N), T(O), T(P), T(Q), T(R)

FLUENCES --

FL(I), FL(J), FL(K), FL(L), FL(M), FL(N), FL(O), FL(P), FL(Q), FL(R)

FIOW DIAGRAM OF STATIC ANALYSIS

BEGIN

↓

GEOMETRIC MODELING OF CAP CAVITY PLATE

↓

SPECIFYING MATERIAL AND PROPERTIES.

↓

DISCRETIZE COMPONENT OF CAP CAVITY PLATE.

↓

APPLYING LOADS AND CONSTRAINTS.

↓

TRANSFORMATION OF THE MODEL INTO EQUIVALENT MATERIAL.

↓

DETERMINING THE DISPLACEMENTS AND STRESSES.

↓

DETERMINING FOS AND MOS FOR STRENGTH

↓

END

Fig-4.5: flow diagram of static analysis

4.14 GEOMETRIC MODELLING:

Modelling has been carried over in pro-engineering software.

The parts drawn in pro-e are:

- The cap.
- Core and cavity extraction.
- Injection mould base assembly and.
- Detailed drawing.

4.14.1 MODELING OF THE CAP:

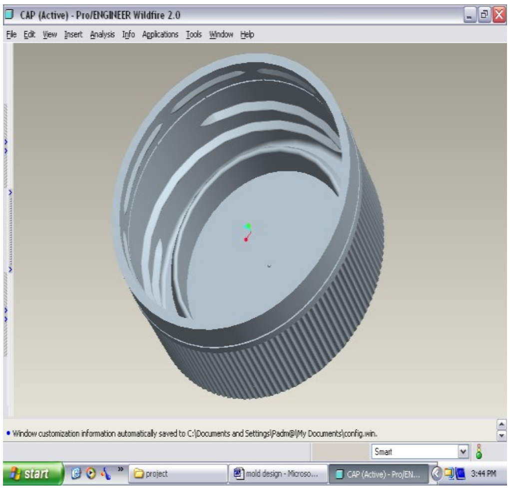

FIG-4.6: 3-D MODEL OF CAP

Sketch of the cap is done in the sketcher part of the pro-engineering. The section of the cap is revolved to 360^0 about the central axis to obtain 3d model of cap as shown in fig-4.6. The cap inner wall and outer wall is inclined angle 92^0.

4.14.2 CORE AND CAVITY EXTRACTION:

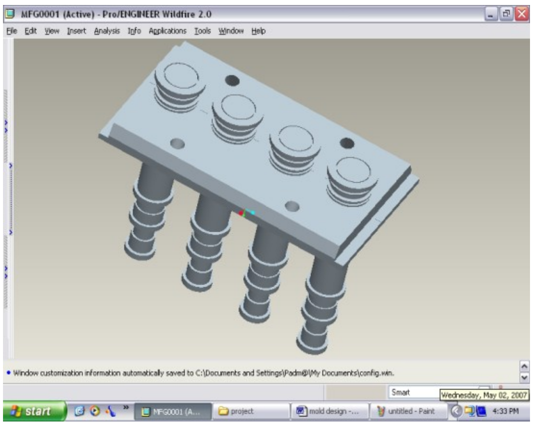

FIG-4.7: CORE AND CAVITY

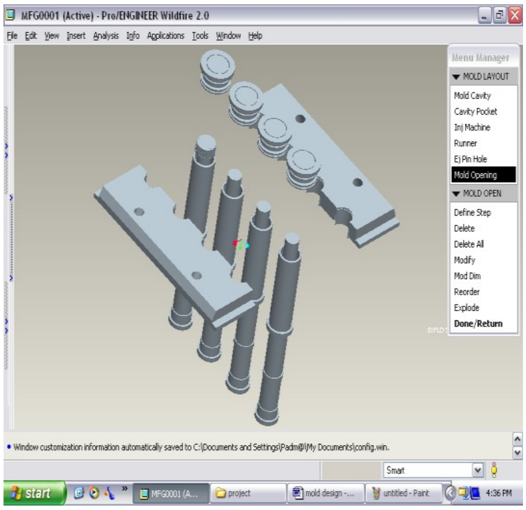

FIG-4.8: CORE AND CAVITY MOULD OPENING

Sketch of the core and cavity is done in the sketcher part of the pro-engineering. The section of the core and cavity is revolved to 360^0 about the central axis to obtain 3d model of core and cavity as shown in fig-4.7-4.8.

FINITE ELEMENT MODELOF CAP-CAVITY-PLATE:

ANALYSIS OF THE CAP IS CARRIED OVER IN FOLLOWING STEPS.

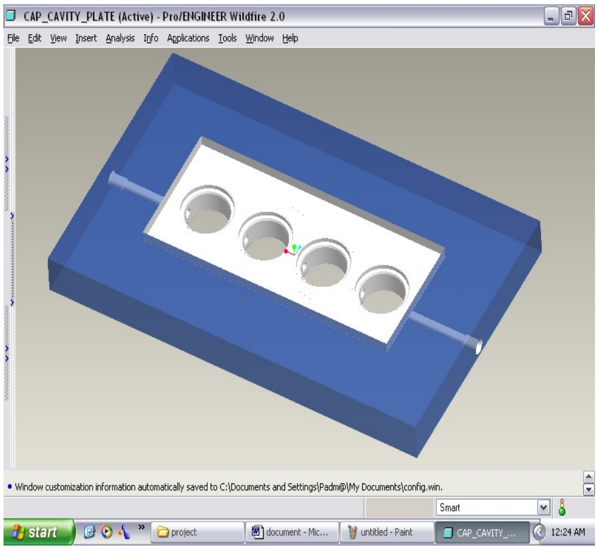

FIG-4.12: CAP CAVITY PLATE

Cap cavity plate model has been modelled in the pro-engineer as shown in fig-4.12.for performing the analysis over the cap cavity plate a finite element model is necessary. In analysis the meshing of the cap cavity plate components is difficult and evens the mesh quality is not maintained for acquiring the results. In order to get the good quality mesh and to maintain the tetrahedron elements, the cap cavity plate is meshed in hyper mesh 11.0

Hyper mesh 11.0 is the product from Altair hyper works. It is the commercially available software package. It mainly used for the finite element modelling of the components. Meshing of the cap cavity plate is done by the following

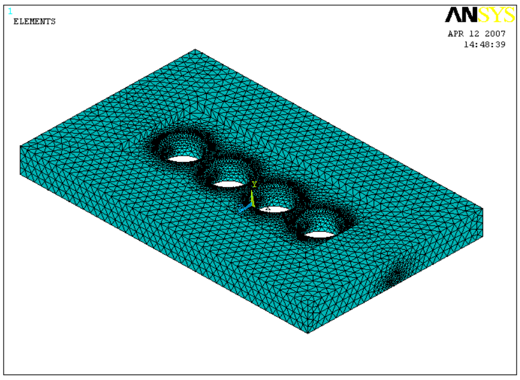

Fig-4.13: meshed model

1) **cap cavity plate as shown in fig-4.13 is retrieved in hyper mesh.**
2) **Solid 10 node 92 element type is created for structural analysis.**
3) **Solid 10 node 87 element type is created for thermal analysis.**

RESULTANT DISPLACEMENT AND VON MISES STRESS FOR LOAD 45N/MM^2.

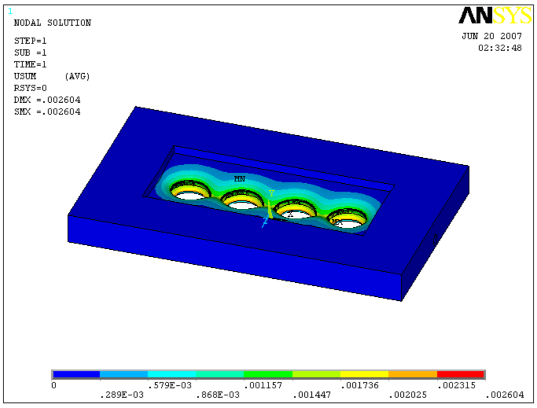

FIG-5.11: DISPLACEMENT CONTOUR

From the resultant displacement contour fig-5.11 the maximum displacement is 0.002604 mm is at in side of cap. And minimum displacement is 0.289E-03 mm where the thickness is 36mm.

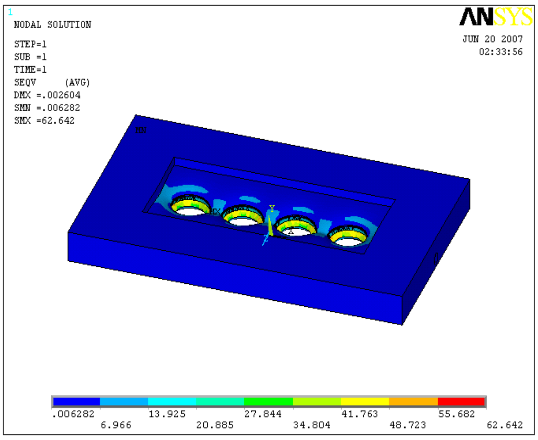

FIG-5.12: VON MISES STRESS CONTOUR

From the resultant von misses stress contour fig-5.12 the maximum stress is 62.642n/mm^2. And minimum stress is 0.006282n/mm^2 and the thickness of the plate is 36mm.

5.8 RESULTANT DISPLACEMENT AND VON MISES STRESS FOR LOAD 50N/MM^2.

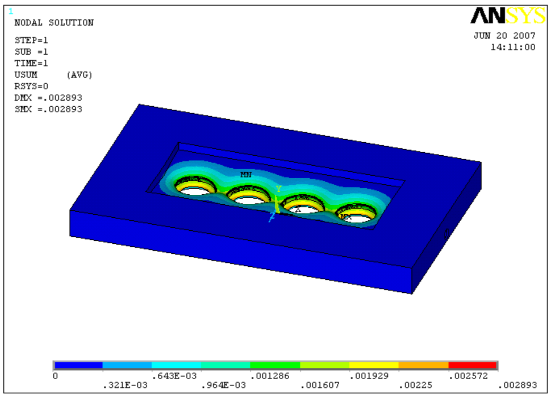

FIG-5.13: DISPLACEMENT CONTOUR

From the resultant displacement contour fig-5.13 the maximum displacement is 0.002893 mm is at in side of cap. And minimum displacement is 0.321E-03 mm where the thickness is 36mm.

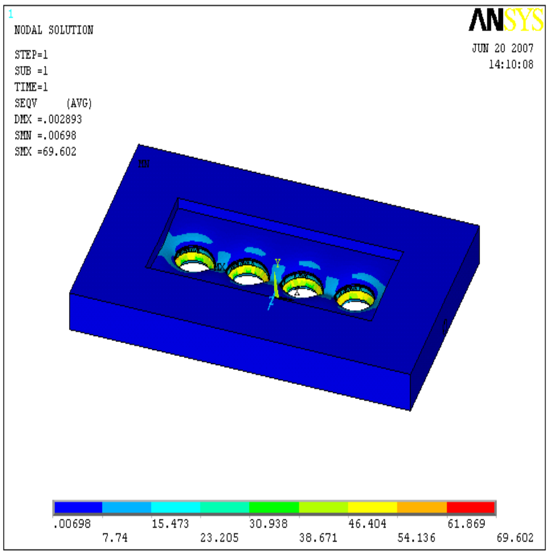

FIG-5.14: VON MISES STRESS CONTOUR

From the resultant von mises stress contour fig-5.14 the maximum stress is 69.602 n/mm^2. And minimum stress is 0.00698 n/mm^2 and the thickness of the plate is 36mm.

5.9 VARIATION OF DEFLECTION WITH LOAD:

TABLE-5.2: LOAD WITH DEFLECTION

LOAD (N/MM^2)	DEFLECTION (MM)
32	**0.001852**
36	**0.002083**
38	**0.002199**
40	**0.002315**
42	**0.002430**
45	**0.002604**
50	**0.002893**

TABLE-5.2 SHOWS THE VARIATION OF LOAD AND DEFLECTION

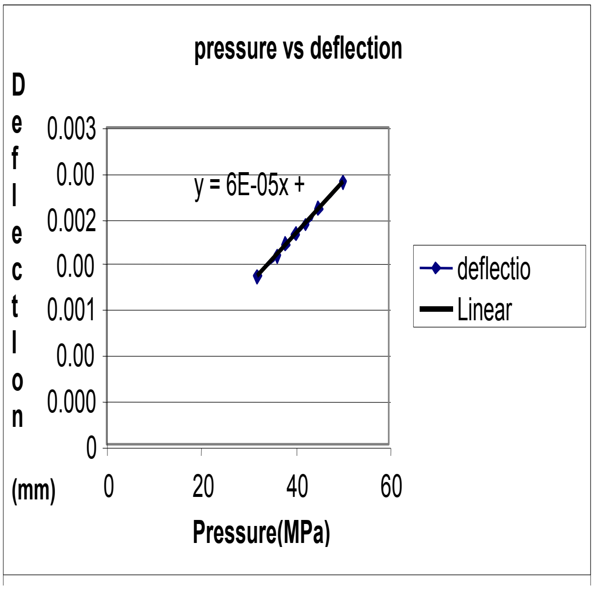

Fig-5.15: Variation of deflection with pressure

From the graph as shown in fig5.15 the x- axis is represented by pressure load in n/mm^2 and the y-axis is represented by deflection in mm. From the graph it is clear that the pressure is directly proportional to deflection. As the pressure increases along the x-axis the deflection increases along the y-axis. So there is no plastic deformation in mould it is maintaining the elasticity only as the curve is linear. So structure will be safe.

THERMAL GRADIENT:

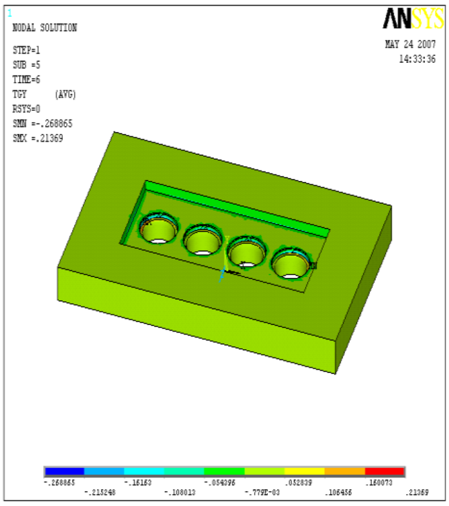

FIG-5.22: THERMAL GRADIENT

AS SHOWN IN FIG-7.2.5 THE MAXIMUM THERMAL GRADIENT IS 0.21369W/MM^2. AND THE MINIMUM THERMAL GRADIENT IS -0.268865W/MM^2.

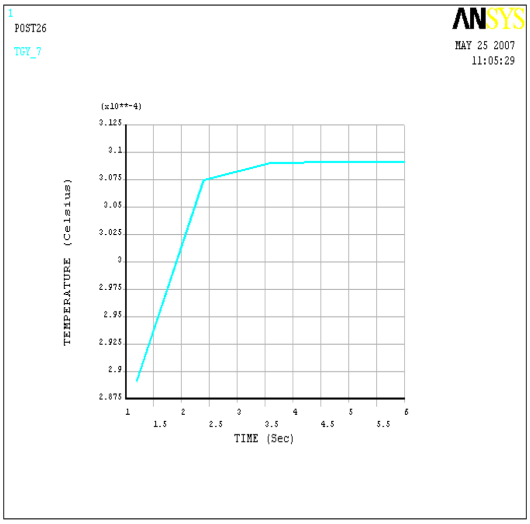

FIG-5.23: VARIATION OF TEMPERATURE WITH TIME (THERMAL GRADIENT)

From the graph as shown in fig-5.23 the x- axis is represented by time in sec and the y-axis is represented by temperature in ^{0}c.

5.16 THERMALGRADIENT VECTOR SUM:

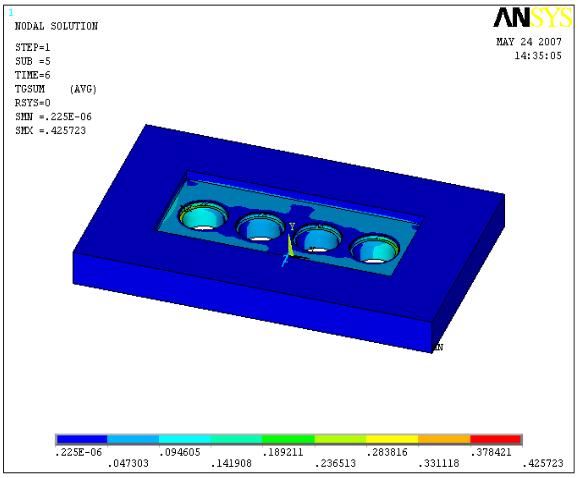

FIG-5.24: THERMAL GRADIENT VECTOR SUM

As shown in fig-5.24 the maximum gradient vector sum is 0.425723w/mm^2. And the minimum thermal gradient vector sum is 0.225e-06 w/mm^2.

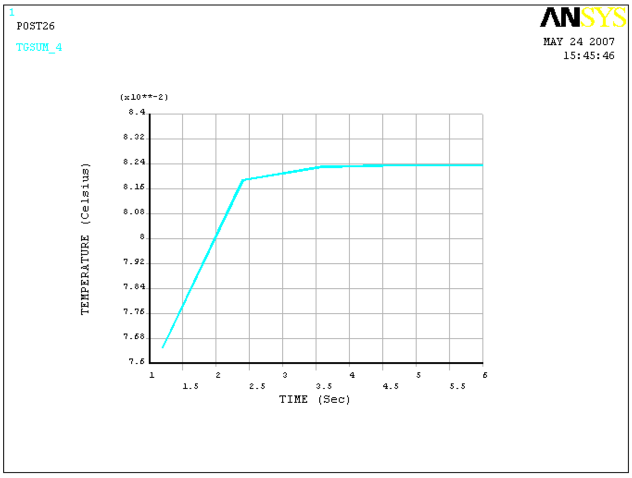

FIG-5.25: VARIATION OF TEMPERATURE WITH TIME (THERMAL GRADIENT VECTOR SUM)

From the graph as shown in fig-5.25 the x-axis is represented by time in sec and the y-axis is represented by temperature in ^{0}c.

CONCLUSIONS

Static analysis and thermal analysis is carried over the cap cavity plate. The cap cavity plate is analyzed for different pressure load cases. A global finite element analysis (FEA) is carried out to arrive at the stresses and deformation of plate.

At a pressure of 40n/mm^2 the maximum displacement is 0.002315 mm and the maximum stress is found to be 55.682n/mm^2.

Stresses developed for a pressure of 40n/mm^2 are less than the yield strength (834n/mm^2) of the material p20 steel. Hence it is concluded that the mould base assembly is safe. From thermal analysis it is observed that the maximum thermal flux is 0.011405w/mm^2.

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