To Study the Effect of Thermal Properties of a Casting Inside a Composite Mold Using an APDL Programming

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Abstract: ***To make the machine and machine components sudden fail-proof it is required to manufacture them with flaws as minimum as possible. There are many methods of manufacturing of an object and the appropriate method of manufacturing is chosen as per the object's topology, point of application and type of performance. In the present work casting process has been investigated. To do the casting process with minimum errors it is required to predict casting flaws prior the actual process by a numerical analysis method. In the present work, iron casting in a sand mold and in a composite mold made of sand and mullite has been simulated in numerical simulation software named ANSYS. The simulations have been done to predict temperature distribution of the casting as well as defects raised during solidification. The most important aspect of the present work is that the simulations have not been done in ANSYS by creating FEA model of the problem manually. In the simulation FEA modeling has been done through 'ANSYS Parametric Design Language' programming which also known as APDL programming. Development of this program facilitates researchers to work with variety of input data with very ease and in minimum time.***

Keywords: Mullite, Mold, APDL.

1. Introduction

Casting is defined as the process whereby molten material is poured or forced into a mould and allowed to harden. When the metal solidifies, the result is a casting - a metal object conforming to that shape. A great variety of metal objects are also moulded at some point during their manufacture.

The most common type of mould is made of sand and clay, sand with cement, ceramics, metals, and other materials are also used for moulds. These materials are packed over the face of the pattern (usually made of wood, resin or metal) that forms the cavity into which the molten metal is to be poured. The pattern is removed from the mould when its shape is able to be retained by the mould material. Moulds are usually constructed in two halves, and the two halves are joined together once the pattern has been removed from them. Pins and bushings permit precise joining of the two halves, which are enclosed in a mould box. The metal is then poured into the mould through special gates and is distributed by runners to different areas of the casting. The mould must be strong enough to resist the pressure of the molten metal and sufficiently permeable to permit the escape of air and other gases from the mould cavity; otherwise, they remain as holes in the casting. The mould material must also resist fusion with the molten metal, and the sand at the mould surface must be closely packed to give a smooth casting surface.

Modern foundries capable of large-scale production are characterized by a high degree of mechanization, automation, and microprocessors allow for the accurate control of automated systems. Advances in chemical binder have resulted in stronger moulds and cores and more accurate castings. Purity and accuracy are increased in vacuum condition; further advances are expected from zero-gravity casting in space.

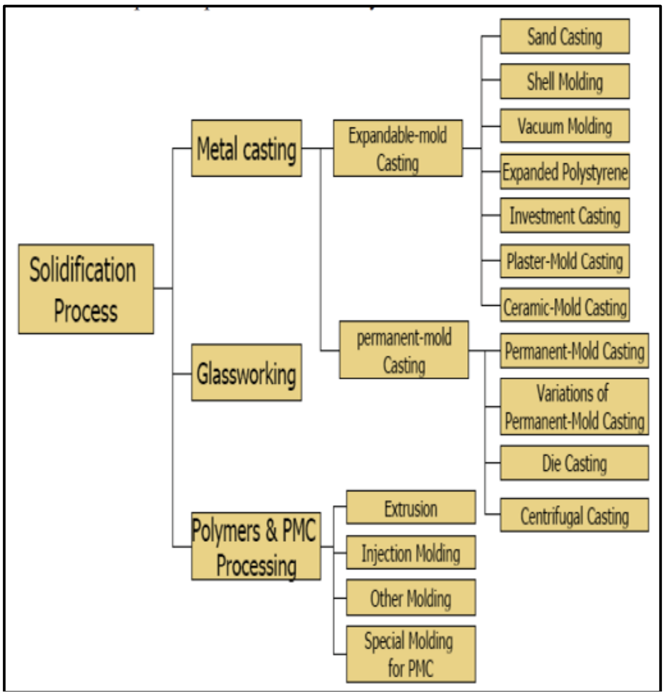
1.1 Sand Casting

Sand-casting is widely used for making cast-iron and steel parts of medium to large size in which surface smoothness and dimensional precision are not of primary importance. The first step in any casting operation is to form a mould that has the shape of the part are to be made. In different processes, a pattern of the part is made of some material such as wood, wax and metal or polystyrene and refractory moulding material is formed around this. For example, in green sand casting, sand combined with a binder such as water and clay is packed around a pattern to form the mould. The pattern is removed, and on top of the cavity is placed a similar sand mould containing a passage (called a gate) through which the metal flows into the mould. The mould is designed so that solidification of the casting begins far from the gate and advances toward it, so molten metal in the gate can flow in to compensate for the shrinkage that accompanies solidification. Sometime risers are added to the casting to provide reservoirs to feed shrinkage. After solidification is done, sand is removed from the casting, and gate is cut off. If cavities are intent to be left in the casting e.g. to form a hollow part--sand shapes called cores are made and suspended in the casting cavity before the metal is poured.

1.2 Solidification of Casting

The mechanism of solidification of alloys or metals and its control for obtaining sound castings is the most important problem of foundry men. For better understanding the solidification mechanism is essential for preventing defects due to shrinkage of the metal. In solidification process, cast form develops cohesion and acquires structural characteristics. The process of solidification affects the properties of the castings because a casting makes a metallographic structure which is determined during solidification.

Table 1.1: Solidification Process



1.3 Concept of Solidification of Metals

A metal in molten states possess high energy. As the melt cools, it loses energy to form crystals. When heat loss is more rapid near mould walls than any other place, first sub microscopic metal crystallites called nuclei form here. Melting experiences difficulty in starting of crystallites, if no nuclei in the form of impurities are present to start crystallization. However in this conditions melt under-cools and thus nuclei or seed crystals form. Crystal growth proceeds with release of energy at crystal melt interface. Dendrite growth takes place by the evolution of the small arms on the original branches of individual dendrites. As solidification proceed, more and more arms grow on an existing dendrite and also more and more dendrites form until the whole melt is crystallized.

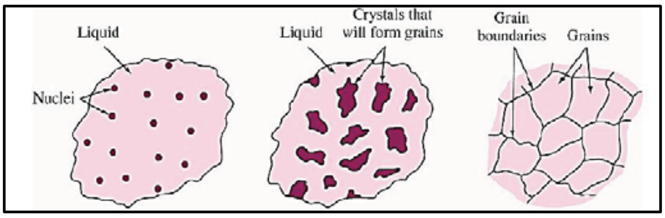


Fig. 1.1 Crystal growth proceeding in solidification.

As solidification proceed, more and more arms grow on an existing dendrite and also more and more dendrites form until the whole melt is crystallized.

Fig 1.2: Dendritic growth in solidification

Liquid metal cools from point A to point B. From point B to C, the melt liberates latent heat of fusion; temperature remains constant. The liquid metal starts solidifying at point B and it is partly solid at any point between B and C and at point C the metal is purely solid. From point C to D, the solid metal cools and tends to reach room temperature. Slopes of AB and CD depend upon the specific heats of liquid and solid metals respectively.

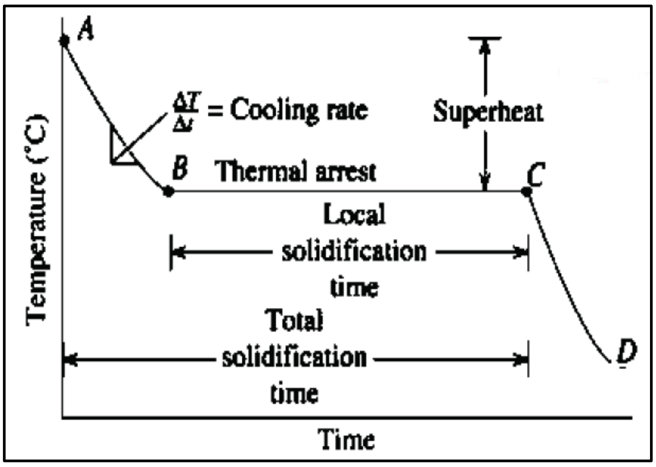


Figure 1.3: Time Temperature plot of solidification

Nucleation of solid does not start at point B (i.e normal solidification temperature) but it does so at C i.e after the liquid metal has supercooled. This phenomenon is known as supercooling or undercooling. Besides pure metals, supercooling are occur in alloys also, e.g. Gray cast iron.

2. Analysis of Iron Casting with Sand mold

In their work M. M. Pariona and A. C. Mossi considered a channel shaped cast object which was cast using pure iron. The drawing and solid model of the cast has been shown below. As per the below drawing a solid model has been generated in Pro/Engineer software to give a clear 3-Dimensional view of the cast-mold assembly. Here only half section of the whole cast-mold assembly has been modeled to represent the assembly vividly. Blue portion is the cast object and the yellow portion is the mold object. The sprue portion though has been modeled but has not been considered in the simulation.

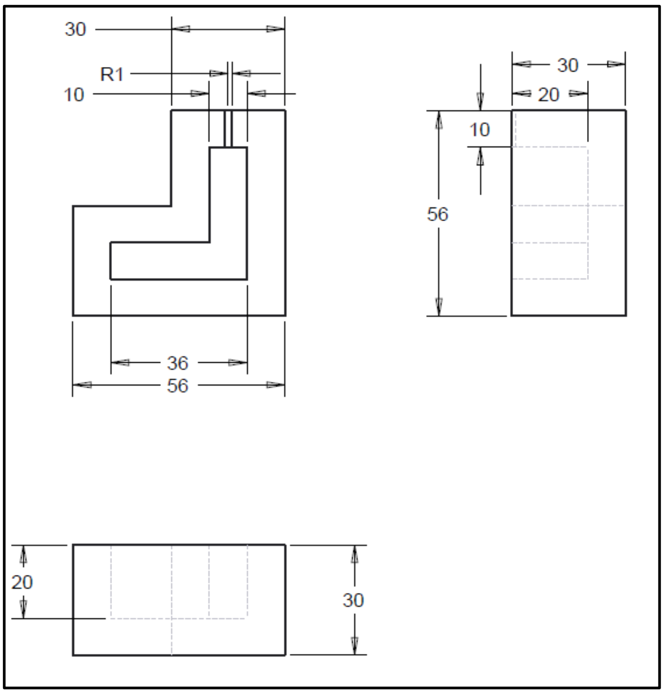


Fig 2.1: Drawing of cast object with mold

The above model has been generated as per the model presented in the work of M. M. Pariona and A. C. Mossi which has been shown in figure 2.2 below.

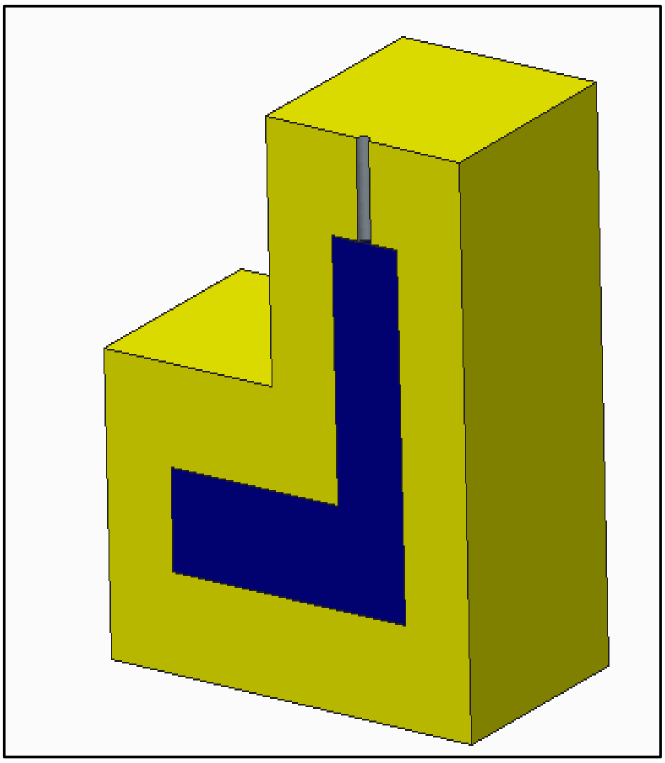


Fig 2.2a Dimensional model of the cast-mold assembly

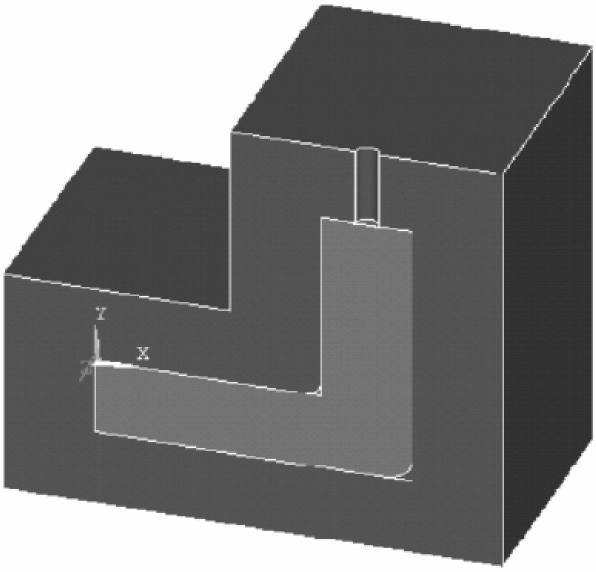


Fig.2.2b Dimensional model of the cast-mold assembly

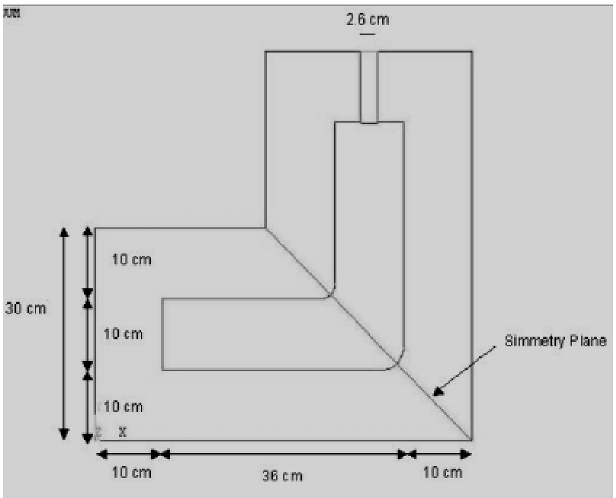


Fig 4.2c Dimensional model of the cast-mold assembly

The details of the pure iron corner piece as per the work of M. M. Pariona and A. C. Mossi (Reference [8]) has been shown below. Now to show the assembly of the corner piece inside the sand mold clearly, the sand mold part of the whole assembly has been made transparent in the 3-D modeling software Pro/Engineer and has been presented below.

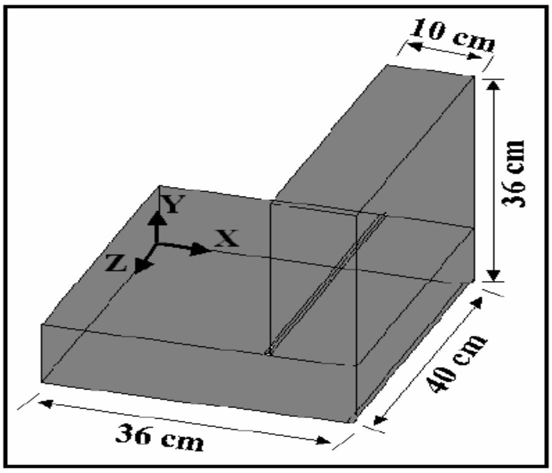


Fig. 2.3 Dimensional model of the pure iron corner piece

Now to predict the temperature distribution of the cast-mold assembly after 1.5 hours or 5400 seconds of pouring hot and malted pure iron at 1923 K, a transient thermal simulation has been done in ANSYS software. Temperature distribution evaluated from this simulation has been verified with the result found out by M. M. Pariona and A. C. Mossi in their work

In Pre-Processor stage following jobs are done:
1) Modeling of the simulation topology.
2) Selection of Elements type.
3) Declaration of relevant material properties.
4) Discretization and Mashing of the topology.
5) Setting of boundary condition and Load data.

3. Modeling of the simulation topology

Due to the symmetrical shape of the cast body half portion of the whole object has been considered for the transient thermal analysis in the FEA software ANSYS. Following figure shows the topology of the object in ANSYS for simulation.

In the figure 3.1 area with cyan color represents cast object whereas area with purple color represents sand mold portion. These two area has been assembled in ANSYS using 'Glue' command which connect both the areas for simulation but does not convert two areas in a single type because both are of different types, one of pure iron and another of silica. One thing is to be mentioned over here that in ANSYS the dimension of the symmetric geometry has been considered in 'm' whereas dimensions in the drawing in figure 3.1 has been mentioned in 'mm'.

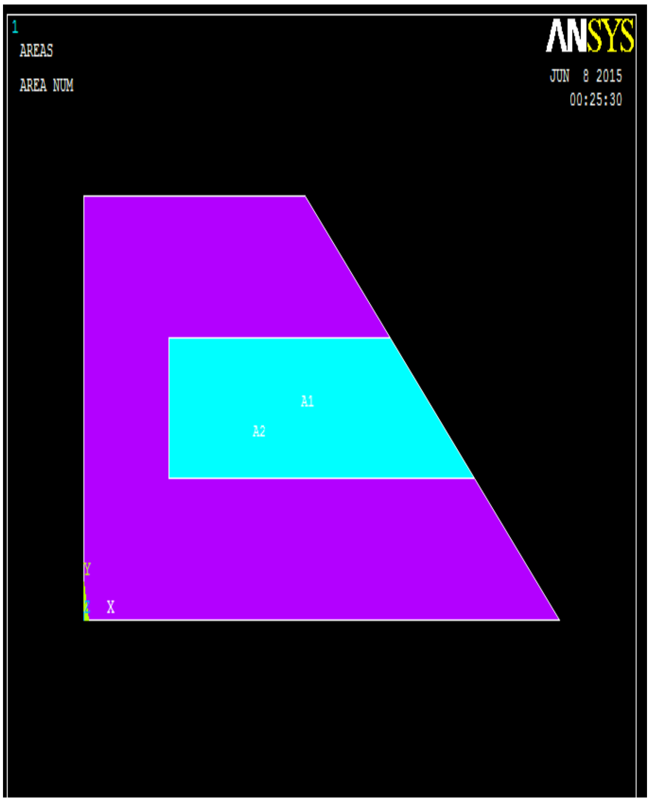


Fig 3.1Topology or Geometry of the object for simulation in ANSYS.

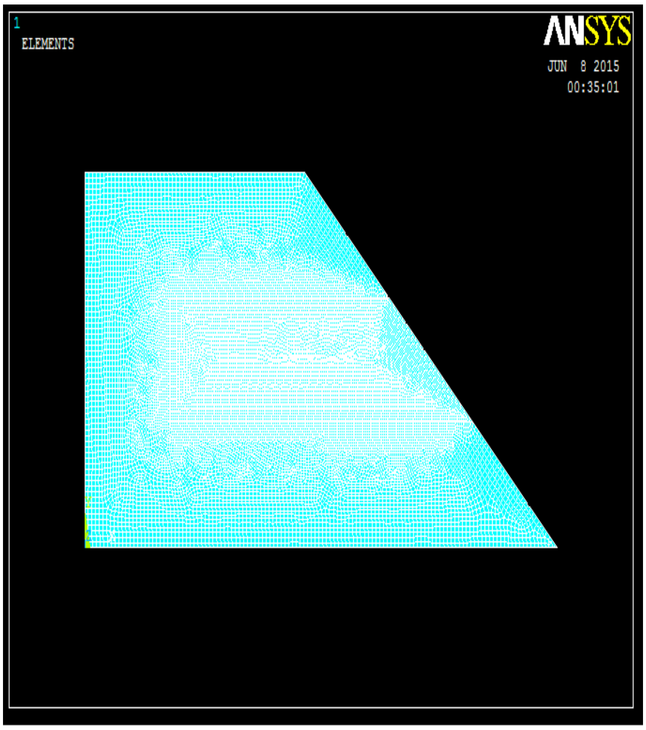


Fig 3.2 Meshed Topology or Geometry of the object for simulation in ANSYS.

Here meshing of the topology has been done with two different discretizing scheme. The cast object part has been meshed with 0.002 m of element length and the sand mold part has been meshed with 0.0045 m of element length. Here to mesh the topology in ANSYS 'PLANE 55' element has been used which is a thermal solid element. Following figure depicts the fact that how an element is selected in ANSYS for simulating an object.

After meshing the object geometry material properties have been declared. Here two types of material have been used, pure iron for the cast part and silica for sand mold. As during solidification temperature of the cast part is reduced to great extent so material properties of pure iron become function of temperature. Material properties of pure iron and silica have been mentioned below and these data has been referred from the work of M. M. Pariona and A. C. Mossi. In the similar way corresponding data for silicon also have been incorporated in ANSYS.

After mentioning the material property data for pure iron as well as silica, temperature boundary condition has been mentioned. Here convection boundary condition has been set on the outer surface of the mold where mold is in contact with atmosphere. In this boundary condition convective heat transfer coefficient has been mentioned as 11.45 $W/m^2.K$ and bulk temperature has been considered as 300K.

These data has been collected from the work of M. M. Pariona and A. C. Mossi. For transient thermal simulation initial temperature has been set as 1923 K because liquid iron has been poured at 1923K temperature which is 111K super heat as melting temperature of pure iron is 1812K.

Properties of the pure iron			
Temperature (K)	Enthalpy (MJ/m^3)	Temperature (K)	Thermal conductivity ($W.m^{-1}.K^{-1}$)
298	0	273	59.5
373	200.75	373	57.8
473	498.87	473	53.2
573	831.83	746	49.4
673	1199.61	673	45.6
773	1602.22	773	41.0
873	2039.65	873	36.8
973	2511.91	973	33.1
1033	3200.23	1073	28.1
1073	3412.0	1273	27.6
1183	4120.86	1473	29.7
1273	4453.89		
1373	4849.96		
1473	5273.45		
1573	5724.36		
1673	6299.75		
1812	9317.24		
1812	9676.0		
Density ($kg.m^{-3}$)	7870		
Melt temperature 1812 K			
Properties of the industrial sand, AI 50/60 AFS			
Specific heat		1172.3 $J/(kg.K)$	
Thermal conductivity		0.52 $W/(m.K)$	
Density		1494.71 kg/m^3	

Fig 3.3: Material properties of Pure Iron

Table 4.1: Transient analysis parameters

Total time of simulation	1.5 hours or 5400 seconds
Time step	5 seconds
Maximum Time Step	10 seconds
Minimum Time Step	1 sec

After simulation of the cast-mold assembly for 1.5 hours of solidification, temperature distribution has been evaluated for whole the region of cast-mold geometry and also separately for the cast part. Following are the figures of temperature distribution of whole the assembly and separately of the cast part.

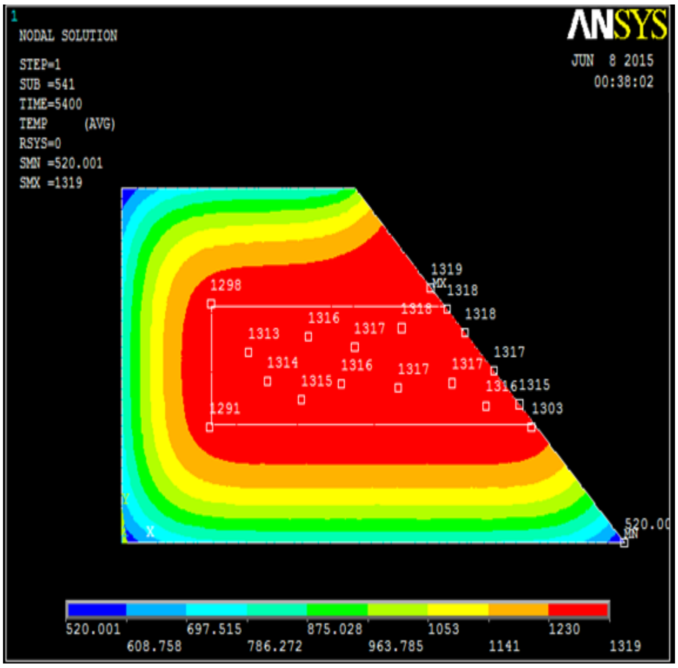


Fig. 3.4 Temperature at different points of the cast-mold assembly.

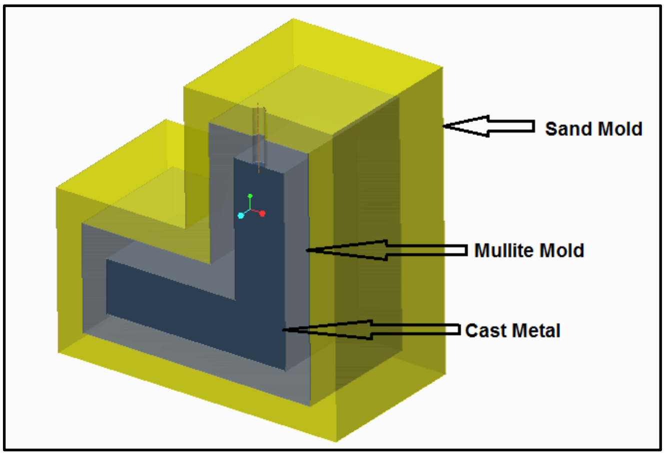


Fig. 3.5 3D Model of the composite mold made of sand and mullite together.

4. Conclusion

For analysis of any casting process with many types of mold materials in combination needs many simulations with a lot of input variable combinations. For better product out of any casting process it is necessary to make the molding free of flaws as much as possible. So, it is needed to derive or to find out optimized molding parameters to cast a product with minimum defects.

In this present era of high competitive market it is not possible spend much time in the simulation process to find out optimized mold parameters by trial and error method. So to minimize the lead time it is required to do the analysis in ANSYS by it programming language named 'ANSYS PARAMETRIC DESIGN LANGUAGE (APDL)'. With the help of this programming one can give different input parameters and all the intermediate process of analysis is done in flicker of second minimizing the time required for simulation.

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