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Design &Analysis of Pure Iron Casting with Different Moulds

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ABSTRACT : *In the present work it has been shown that FEA software like ANSYS may play an important role in predicting cast defect before the actual casting. Transient thermal analysis and Couple-Field analysis in ANSYS can predict temperature distribution and thermal stress distribution in the casting after solidification very accurately. This fact has been proved by validating a transient thermal analysis which has been published in a reputed journal. After validating the thermal analysis, work has been extended to Couple-Field Analysis for thermal stress and shrinkage.*

After doing Couple-field analysis on sand mold, few modifications have been simulated and tested whether they are better than the configuration considered in the base paper. As first modification sand has been replaced by mullite and it has been seen that the mold shrinkage is less but the cast shrinkage is more. Thermal stress in the mullite mold is less than the sand mold. For the sand-mullite composite mold shrinkage is least as well as shrinkage for the cast is also least. But the thermal stress is more than the mullite mold.

Keywords: *Cast Solidification, Sand mold, Mullite Mold, Composite Mold, Transient thermal analysis, Couple-field analysis, ANSYS.*

I. INTRODUCTION

Technological difficulties involved in casting processes vary considerably according to the metal's melting temperature characteristics, which in turn are related to the physicochemical properties and structures of metals and alloys. These difficulties also involve a series of properties, which include differences in chemical activities between the elements that constitute the alloy, solubility of the gases, method of solidification among the chemical elements, type of molding, and coefficients of solidification shrinkage. On the other hand, the cooling process also affects the flow of cast metal, influencing the mold filling and stability, allowing the occurrence of cooling stresses and properties changes in the final product, and producing variations in the geometrical dimensions, the shape of the surface finish and the quality of the cast part.

An investigation was done by YIN-HENC CHEN and YONG-TAEK IM on the prediction of shrinkage a permanent mold casting in sand mold in the year of 1990 and their work published in Int. J. Mach. Tools Manufacture (Vol. 30, No. 2, pp. 175-189).

In the year of 1994 JYRKI MIETI'INEN and SEPPO LOUHENKILPI did a remarkable work on Calculation of Thermophysical Properties of Carbon and Low Alloyed Steels for Modeling of Solidification Processes and they published their work in METALLURGICAL AND MATERIALS TRANSACTIONS B (VOLUME 25B)

A work on Thermal stress and crack prediction was done by L.C. Würker, M. Fackeldey, P.R. Sahm and B.G. Thomas in the year of 1998.

B. J. MONAGHAN and P. N. QUESTED did a work on Thermal Diffusivity of Iron at High Temperature in Both the Liquid and Solid States in the year of 2001 and their work published in the journal named ISIJ International (Vol. 41, No. 12, pp. 1524–1528).

A very good work on Numerical Simulation of Filling Process in Die Casting was done by Y. B. Li and W. Zhou and their work got published in the journal Materials Technology in the year of 2003 (Vol. 18, No. 1, pp. 36-41).

In the year of 2005 a very excellent work was done by M. M. Pariona and A. C. Mossi on Numerical Simulation of Heat Transfer during the Solidification of Pure Iron in Sand and Mullite Molds. This work was published in a very reputed journal named "J. of the Braz. Soc. of Mech. Sci. & Eng." and this work has been referred as a base paper in the present work. The work has been extended in the present thesis over the work of this base paper on the investigation of thermal stain and shrinkage of a pure iron casting in mullite mold and a composite mold made of mullite and sand. Though many works have already been done on thermal and thermo-mechanical simulation of casting process but a thermo-mechanical simulation on a composite mold made of sand and mullite is a new one.

II. DESCRIPTION OF THE PROBLEM

In casting of an object many problems are raised during solidification. One of these problems is internal cracks of the cast object due to compressive stress generated during solidification. This compressive stress is governed by many factors of mold topology. Compressive stress generated during solidification of casting can be controlled by mold thickness, mold materials, combination of different mold materials and layer thickness, draft angle etc. So, before taking decision on above parameters it is needed to know the stress distribution of cast object after solidification. Here in this work a detailed transient (i.e. time dependent) couple-field analysis has been done on a cast object to predict thermal stress in the cast body during solidification. Moreover an investigation has been done in this work on shrinkage and thermal strain with a mold material named mullite and combination of sand and mullite.

III. MATHEMATICAL MODELING OF CAST SOLIDIFICATION

In order to formulate a mathematical model for heat transfer problem during casting, consider superheated liquid metal poured in an investment casting shell. There are two steps in which metal losses their heats,

a. First step in which metal losses its sensible heat (superheat).
b. Second step during which metal losses its heat of fusion (Hf).

Time of solidification is determined separately during each interval using different heat transfer coefficients (HTCs) and then individual times are summed up together to get total time taken for solidification.

1 Sensible Heat Transfer

When metal is poured in investment casting shell, whole of the shell is quickly heated to high temperature (temperature of molten metal), heat transfer also starts subsequently and temperature of metal starts decreasing. As a result of this, temperature of mold starts increasing. During this step total heat transfer from top and walls is

$$Q_t = Q_T \cdot t_1 \qquad (1)$$

Where Qt is the total quantity of heat lost from top and wall, QT is total rate of heat transfer by convection and radiation from top and conduction through walls and t1 is the total time taken for heat transfer (time of solidification in first step).

Heat transfer occurs by three modes namely convection, conduction and radiation; total rate of heat transfer (QT) is summation of rate of heat transfers by each mode.

$$Q_T = Q_{T1} \cdot Q_{T2} \cdot Q_{T3} \qquad (2)$$

where QT1, QT2, QT3 are the rate of heat transfers by convection and radiation from top surface, conduction through walls and convection and radiation from heated mold surface, respectively.

Rate of heat transfer by convection and radiation from top may be written as:

$$Q_{T1} = (h + h_r)_{\overline{T}} \cdot A_T \cdot (\overline{T} - T_\infty) \qquad (3)$$

where $\overline{T} = \frac{1}{2}(T_p + T_m)$, temperature at which HTCs are determined, h and hr are the heat transfer coefficients for free convection and radiation, respectively, AT is area of top surface of mold and Tα is mold temperature. Major portion of heat in this process of heat transfer is lost through top surface thus QT1 is the major rate of heat transfer during solidification. This is the reason; risers of castings are usually covered by some insulating compound or bad heat-conducting medium to keep metal liquid for a longer period of time so that proper feeding of metal could be achieved.

Rate of heat transfer by conduction may be written as:

$$Q_{T2} = \frac{(T_p - T_\infty)}{R_t} \qquad (4)$$

Where Tp and Tα are the inside and outside temperatures of mold and Rt is the thermal resistance of mold wall.

Thermal resistance of the mold here though very high, is not constant, but keeps on changing with change of temperature and contributes towards overall effect of heat transfer.

Similarly, rate of heat transfer again by convection and radiation from outer heated wall of mold may be written as:

$$Q_{T3} = (h + h_r)_{T_s} \cdot A \cdot (T_s - T_\infty) \qquad (5)$$

Where Ts is the surface temperature of the mold, Tα is the outside (surrounding) temperature of the mold [(Tα=Tr), Tr = room temperature], h and hr are heat transfer coefficients (HTCs) for free convection and radiation, respectively, and A is area of heated mold surface towards ambient. This mode of heat transfer has very little contribution towards overall rate of heat transfer during first step, as initially surface of mold is at ambient and gets heated slowly in small increments thus starts transferring heat. This mode of heat transfer also has little contribution due to high thermal resistance of mold material(s), which stops most of heat from coming out of the mold.

Putting the values in Eq. (2)

$$Q_T = (h + h_r)_{\overline{T}} \cdot A_T \cdot (\overline{T} - T_\infty) + \frac{(Tp - T_\infty)}{R_t} + (h + h_r)_{Ts} \cdot A \cdot (Ts - T_\infty) \qquad (6) \qquad (3.6)$$

Total quantity of heat transferred (Qt) is actually the heat lost by metal as its sensible heat, which may be written as

$$Q_t = mCp\Delta T$$
$$Q_t = mCp(Tp - Tm) \qquad (7)$$

Where, Cp is specific heat of metal, Tp and Tm are pouring and melting temperatures of the metal, respectively, and m is the mass of metal being poured.

Combining Eqs. (6) and (7) and putting values in Eq. (1)

$$mCp(Tp - Tm) = (h + h_r)_{\overline{T}} \cdot A_T \cdot (\overline{T} - T_\infty) + \frac{(Tp - T_\infty)}{R_t} + (h + h_r)_{Ts} \cdot A \cdot (Ts - T_\infty) \cdot t_1$$
$$t_1 = \frac{mCp(Tp - Tm)}{(h + h_r)_{\overline{T}} \cdot A_T \cdot (\overline{T} - T_\infty) + \frac{(Tp - T_\infty)}{R_t} + (h + h_r)_{Ts} \cdot A \cdot (Ts - T_\infty)} \qquad (8)$$

This is the expression for the calculations of time for solidification of metal during pouring and subsequent freezing in investment casting molds during step in which it losses all its sensible heat.

Various factors affect this time of solidification during first step such as thermal conductivity of mold material, casting conditions, pouring temperature, specific heat of metal, etc. All these should be taken into account while designing a casting process. Soon after the release of all superheat of metal, second step of solidification begins.

2 Transfer of Heat of Fusion

When metal loses all its sensible heat (superheat) and reaches its melting temperature, a phase transformation occurs and metal starts loosing heat as heat of fusion. This heat transfer continues till whole of the metal solidifies in the mold. This is second step of heat transfer

Like first step of heat transfer, heat again transfers in three modes namely convection, conduction, and radiation. This occurs in a fashion very similar to first step of heat transfer (i.e. from top, walls and heated surface of mold). Thus, total heat transfer from top and walls may be written as:

$$Q_t = Q_T \cdot t_2 \qquad (9)$$

Where Qt is the total quantity of heat lost from top and walls, QT is total rate of heat transfer by convection and radiation from top and conduction through walls and t2 is the total time taken for heat transfer (time of solidification in second step).

Again total rate of heat transfer is the summation of rates of heat transfer by individual modes

$$Q_T = Q_{T1} \cdot Q_{T2} \cdot Q_{T3} \qquad (10)$$

where QT1, QT2, QT3 are the rate of heat transfers by convection and radiation from top surface, conduction through walls and convection and radiation from heated mold surface, respectively.

Quantities QT1, QT2 and QT3 may be determined by use of Eqs. (3) – (5) with the replacement of T with Tm in Eq. (3) as this is the temperature at which HTCs are determined during second step and Tp with Tm in Eq. (4) as this is the reference temperature from which heat is transferred during conduction in second step.

When values are inserted into Eq. (10) following is obtained,

$$Q_T = (h+h_r)_{T_m} \cdot A_T \cdot (Tm - T_\infty) + \frac{(Tm - T_\infty)}{R_t} + (h+h_r)_{Ts} \cdot A \cdot (T_s - T_\infty) \qquad (11)$$

In second step, total quantity of heat transferred (Qt) is actually the heat lost by metal as its heat of fusion, which may be written as

$$Q_t = mHf \qquad (12)$$

Where Hf is heat of fusion of metal and m is the mass of the metal.

Putting values from Eqs. (11) and (12) to Eq. (9)

$$mHf = (h+h_r)_{T_m} \cdot A_T \cdot (Tm - T_\infty) + \frac{(Tm - T_\infty)}{R_t} + (h+h_r)_{Ts} \cdot A_T \cdot (Ts - T_\infty) \cdot t_2 \qquad (12)$$

$$t_2 = \frac{mHf}{(h+h_r)_{Tm} \cdot A_T \cdot (Tm - T_\infty) + \frac{(Tm - T_\infty)}{R_t} + (h+h_r)_{Ts} \cdot A_T \cdot (Ts - T_\infty)}$$

This is the expression for the calculations of time of solidification of metal during the interval when it transforms from liquid to solid state, i.e. the time when metal losses all its heat of fusion. Factors affecting time of solidification during this step are heat of fusion of metal, thermal conductivity of mold, cooling conditions outside mold, surface area of mold exposed to ambient and extent to which mold is heated during first step.

Finally adding Eqs. (8) and (13) yields the final expression for calculating the time of solidification during whole period from liquid to solid,

$$t = t_1 + t_2 \qquad (14)$$

Prime objective in most engineering cases is to achieve a rapid rate of heat transfer as it facilitates fine grain structure in metal which imparts strength and hardness to metal/alloy. This rapid rate of heat transfer may be achieved by use of mold materials with high thermal conductivity, forced convection conditions (blowing of air on the outer surface of the mold) or rapid cooling of mold surfaces (sprinkling of water on mold surface). This rapid rate of heat transfer however, can induce brittleness in alloy along with poor impact properties. Slow rate of heat transfer on the other hand, can induce problems of segregation especially predominant in multicomponent alloys, long columnar grains and softness that are detrimental to its further applications [9]. So, in most practical conditions an optimum rate of heat transfer is desirable which should facilitate a high strength, fine-grained material with good mechanical properties. Mostly this is achieved in conjunction with post casting heat treatment.

IV. THERMAL ANALYSIS OF CAST AND SAND MOLD

In first phase of this work a transient thermal analysis has been done on an assembly of pure iron casting and sand mold. The cast object and mold design has been referred from the work of M. M. Pariona and A. C. Mossi [8]. 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.

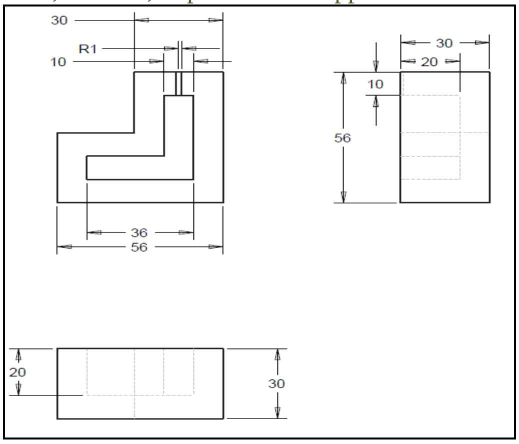

Fig 1: Drawing of cast object with mold.

As per the above 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.

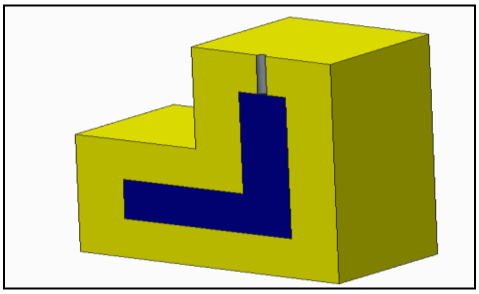

Fig 2: 3-Dimensional model of the cast-mold assembly.

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 (Reference [8]).

Steps followed for the transient thermal simulation in FEA software ANSYS have been explained below with relevant figures.

Simulation in any FEA software is done in three steps, namely Pre-processor, Solution and Post-Processor.

In Pre-Processor stage following jobs are done:

a. Modeling of the simulation topology.
b. Selection of Elements type.
c. Declaration of relevant material properties.
d. Discretization and Mashing of the topology.
e. Setting of boundary condition and Load data.

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.

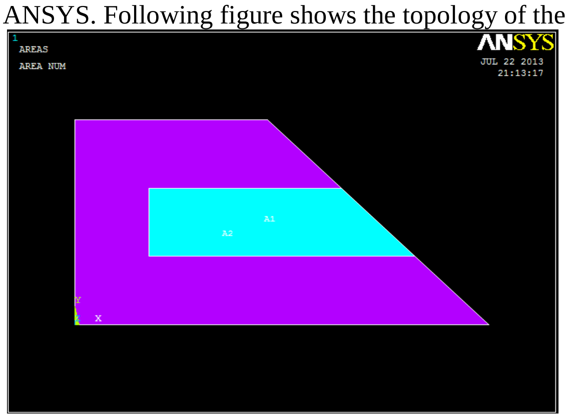

Fig 3: Topology or Geometry of the object for simulation in ANSYS.

In the above figure 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 has been mentioned in 'mm'.

After generating the topology now the topology has been discretized and meshed. Below is the meshed view of the topology.

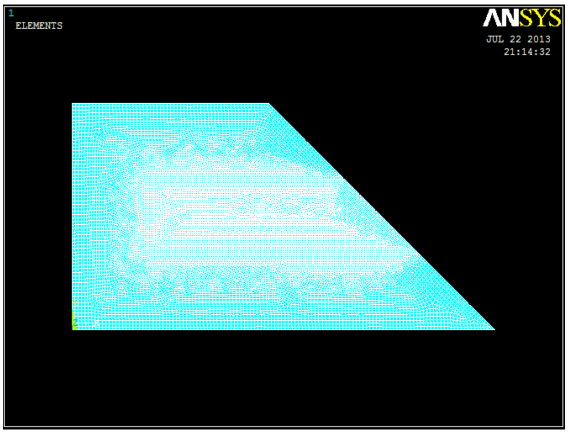

Fig 4: Meshed Topology or Geometry of the object for simulation in ANSYS.

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.

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 (Reference [8]), from reference [13] and from internet.

Table1: Material properties of mold materials

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

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/m2.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 (Reference [8]). 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.

After setting the temperature boundary conditions transient simulation parameter has been set as follows.

Table2: Transient simulation setup

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.

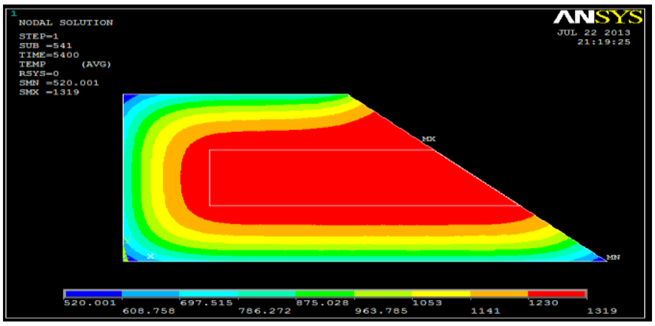

Fig 5: Temperature Distribution of the cast-mold assembly

Above figure shows the contour plotting of temperature distribution of the whole cast-mold assembly and it is clearly depicted from the figure that maximum temperature comes down to 1319 K from 1923K after 1.5 hours of solidification and mold temperature has been raised to 520 K from initial 300 K.
Now the figure below shows temperature at different point in the cast-mold assembly after 1.5 hours of solidification.

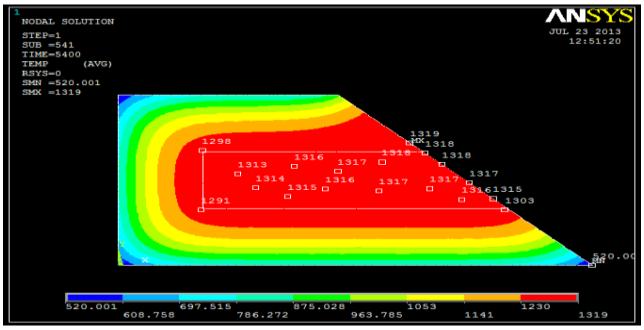

Fig 6: Temperature at different points of the cast-mold assembly.

Above result is very much in accordance with the result found out by M. M. Pariona and A. C. Mossi in their work (Reference [8]). Following figure represents the result published in reference [8].

Now with the same parameters a couple-field analysis has been done in next phase of the work to predict the thermal stress in the cast-mold assembly to take decision about mold geometry.

To know maximum temperature of the mold at different point of time in the due course of solidification a graph has been shown below which has been derived from ANSYS.

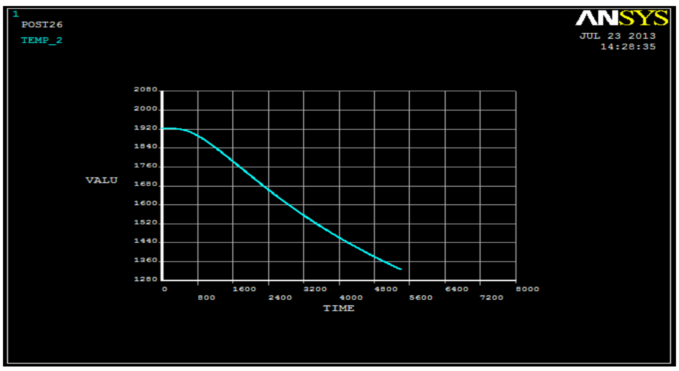

Fig 7: Graph showing max temp at different point of time in solidification process

V. COUPLE-FIELD ANALYSIS OF CAST-MOLD ASSEMBLY WITH SAND MOLD

To predict the defects in cast object and to optimize the mold thickness it is required to predict the thermal stress in the cast-mold assembly. To predict the thermal stress in the cast-mold assembly it is needed to do the couple field analysis in the whole assembly.

In this process, steps for FEA modeling and meshing in ANSYS will be same as described in previous section.

After meshing, thermal properties of both the material i.e pure iron and silica have been incorporated in ANSYS as per the method discussed in previous chapter. The thermal environment has been saved with name 'THERM' and then the environment has been switched over to structural and following structural properties of material have been mentioned in ANSYS.

Table3: Physical properties of cast iron

Young Modulus of pure iron	196×10^{9} N/m^{2}
Poisson's Ratio of pure iron	0.29
Coefficient of linear expansion of pure iron	12×10^{-6} K^{-1}
Density of pure iron	7870 kg/m^{3}
Young Modulus of silica	169×10^{9} N/m^{2}
Poisson's Ratio of silica	0.17
Coefficient of linear expansion of silica	3×10^{-6} K^{-1}
Density of silica	1494.71 kg/m^{3}

After incorporating all the requisite data, a simulation has been done which gives us the result for deflection and thermal stress.

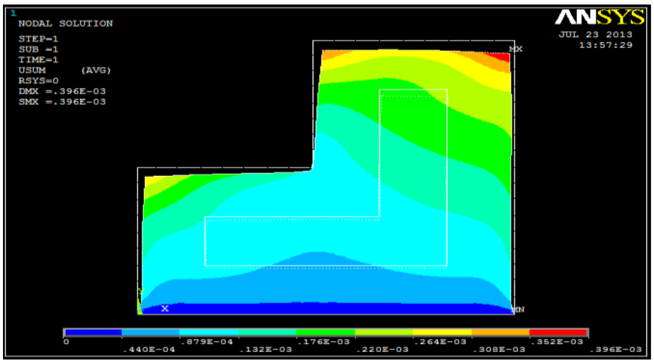

Fig 8: Deflection due to thermal load.

Figure above depicts the deflection in whole the cast object and sand mold assembly due to the thermal load created for solidification. From the above figure it is quite clear that the cast object and sand mold combination will go under a compression due to solidification.

Now due to this solidification the whole assembly will experience a compressive stress which has been presented in the figure below.

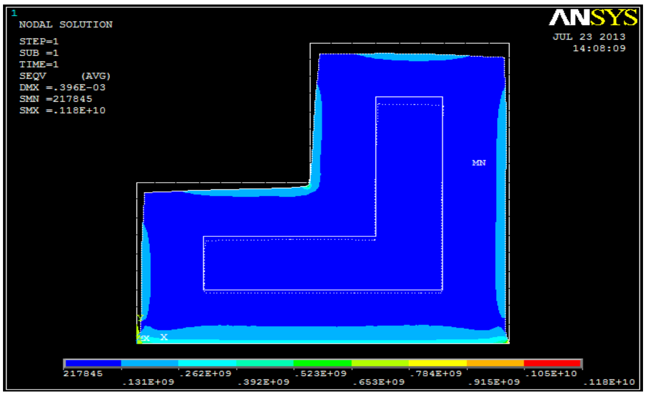

Fig 9: Thermal stress created in the cast-mold assembly.

Figure below shows the compressive stress value at different points in the cast object and sand mold assembly.

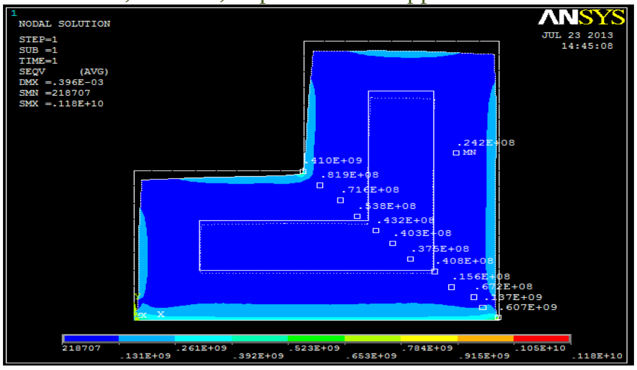

Fig 10: Value of thermal stress created at different points in the cast-mold assembly

VI. COUPLE-FIELD ANALYSIS OF CAST-MOLD ASSEMBLY WITH DIFFERENT MOLD MATERIAL

In previous section it has been shown that FEA software like ANSYS can be used successfully to predict the cast and mold deflections and stresses prior the actual casting process by a numerical simulation. This simulation results actually help a manufacturer to predict correctly about the mold defects out of a present mold design and he or she can correct it before actual manufacturing.
In this section few modifications has been tested by numerical simulation in ANSYS and those results from different modifications have been compared.

Modification-1

In this modification, dimensions of the mold have been kept similar to the dimension discussed in previous chapter but the material has been changed from sand to mullite. Following are the thermal as well as mechanical properties of mullite.

- Specific Heat : 1172.3 J/(Kg.K)
- Thermal Conductivity : 5.86 W/(m.K)
- Density : 3100 kg/m3
- Modulus of Elasticity : 151 GPa
- Poisson's Ratio : 0.20
- Coefficient of linear expansion : 5.4×10-6 / ºC

After simulation following results have been derived and those have been presented below.

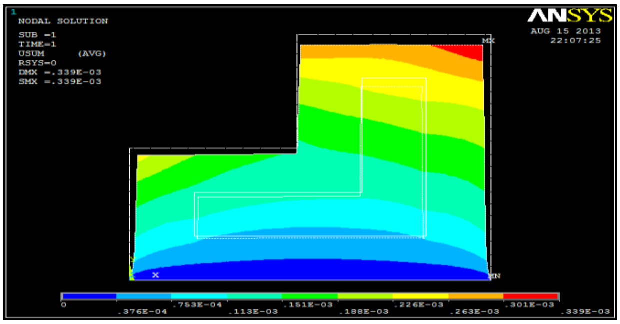

Fig 11: Deflection of the whole mullite mold.

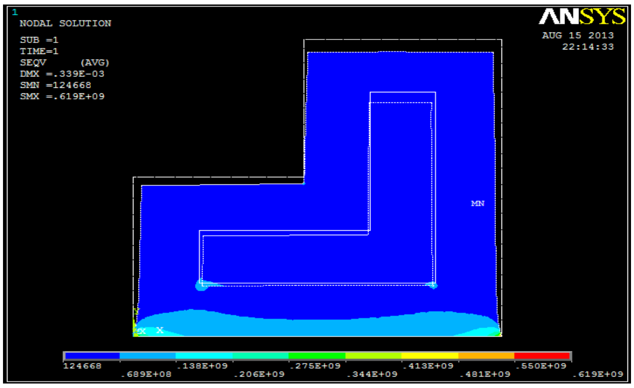

Fig 12: Von-Misses stress on whole mullite mold

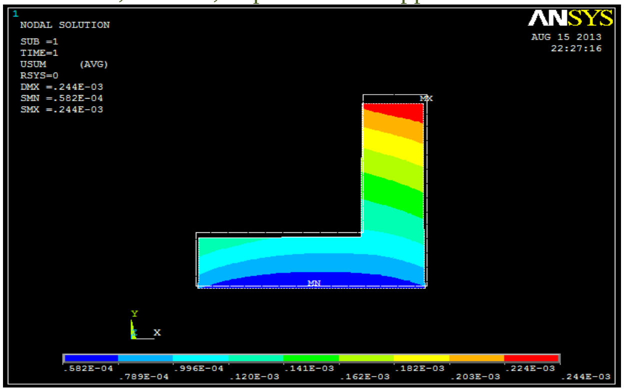

Fig 13: Deflection vector sum of cast part.

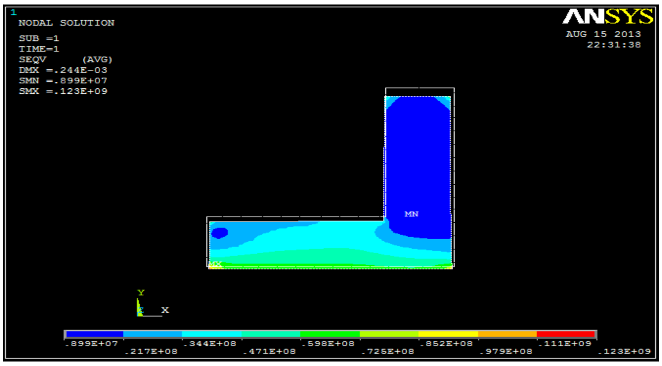

Fig 14: Von Misses stress of cast part.

Modification-2

In this modification, two layers of sand and mullite has been used to create a composite mold. Thickness of each material has been kept half of the total thickness of previously mentioned sand and mullite mold.

Now this composite mold has been modeled in ANSYS in 2D form and meshed with PLANE55 element by a process which has already been discussed in previous section.

Now after the meshing of the FEA model of the composite mold in ANSYS a couple filed analysis has been done and after simulation following results have been derived and those results have been presented below.

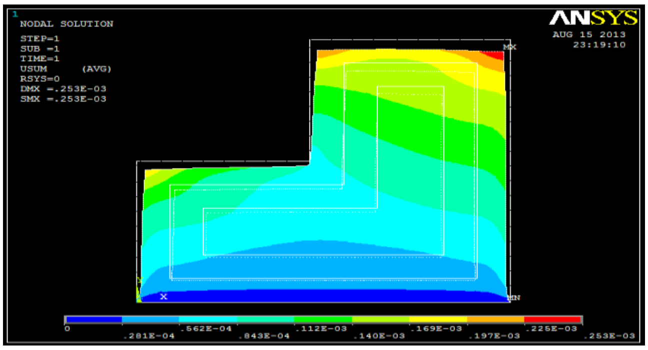

Fig 15: Deflection of whole the composite mold.

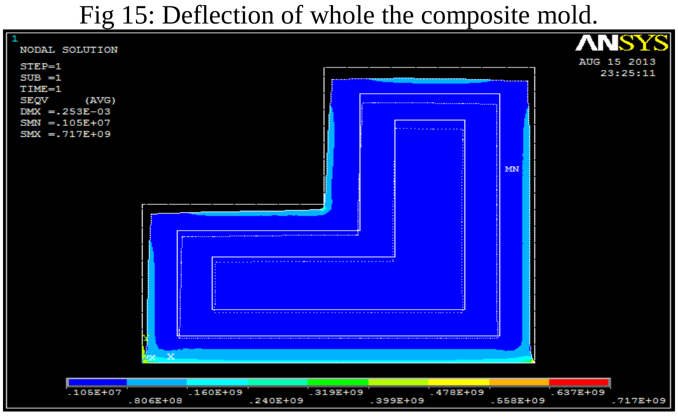

Fig 16: Equivalent stress of the composite mold.

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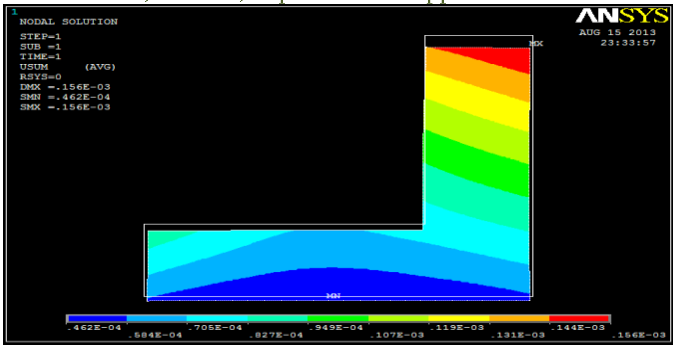

Fig 17: Deflection of the cast part of the composite mold.

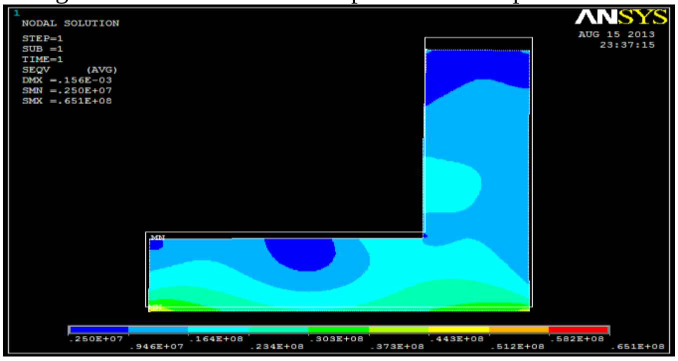

Fig 18: Equivalent stress of the cast part of the composite mold.

Now graphs have been drawn for the following parameters on the symmetry diagonal of sand mold, mullite mold and composite mold respectively.

Maximum shrinkage for whole mold body.
Maximum shrinkage for cast part.
Maximum thermal stress for whole mold body.
Maximum thermal stress for the cast part.

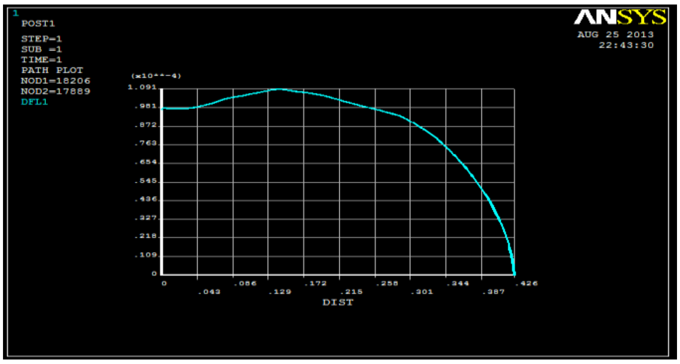

Fig 19: Shrinkage along symmetry diagonal of sand mold

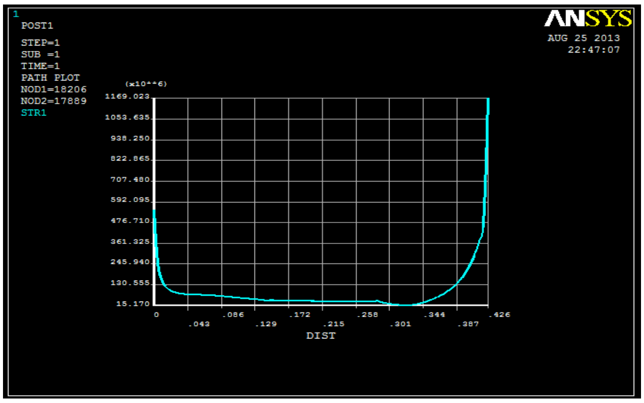

Fig 20: Thermal stress along the symmetry diagonal of the sand mold

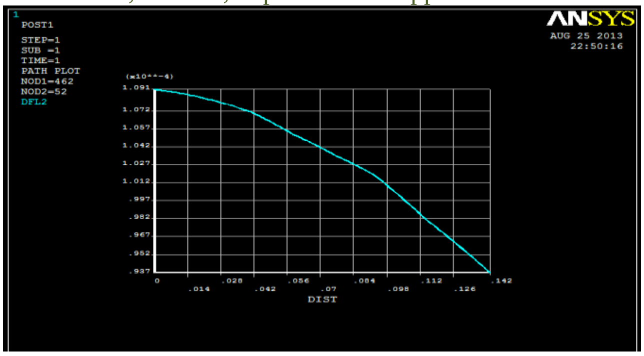

Fig 21: Shrinkage along symmetry diagonal of the cast part of a sand mold

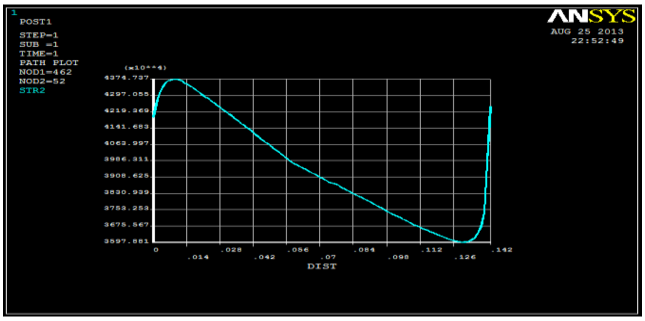

Fig 22: Thermal stress along the symmetry diagonal of cast part of the sand mold

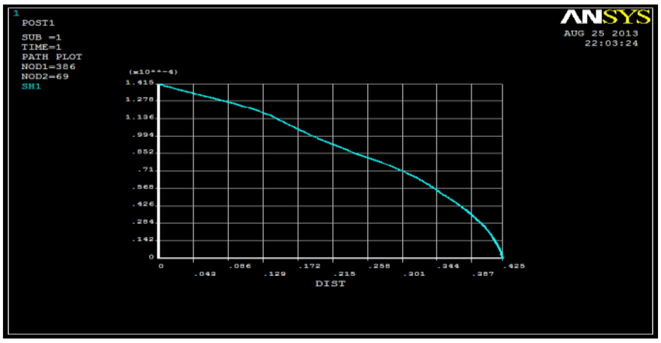

Fig 23: Shrinkage along symmetry diagonal of Mullite mold

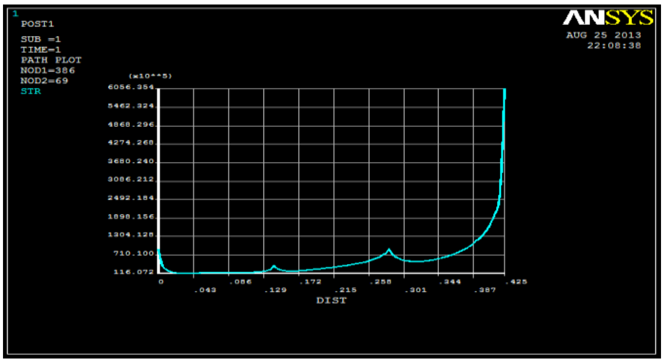

Fig 24: Thermal stress along the symmetry diagonal of Mullite mold

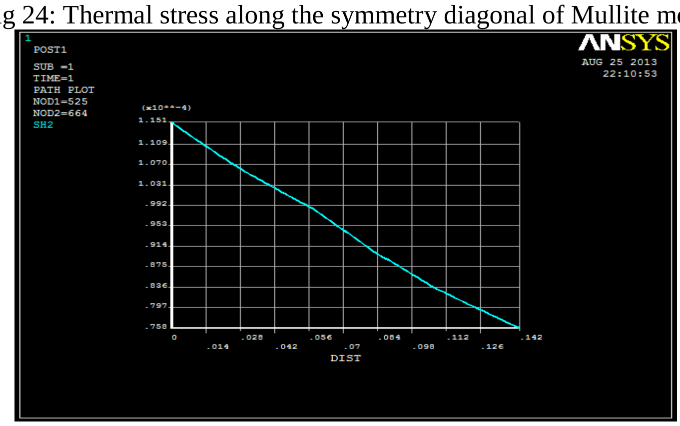

Fig 25: Shrinkage along symmetry diagonal of cast part of Mullite mold

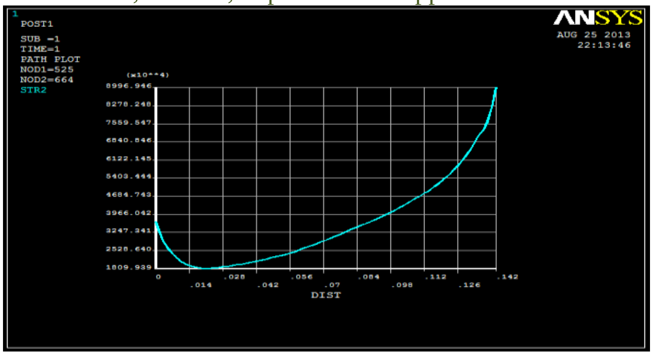

Fig 26: Thermal stress along the symmetry diagonal of cast part of the Mullite

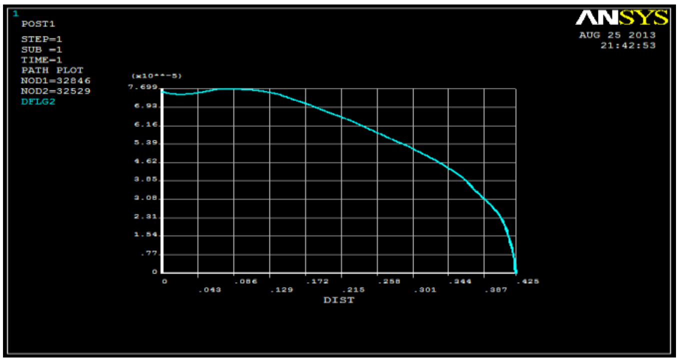

Fig 27: Shrinkage along symmetry diagonal of composite cast-mold combination

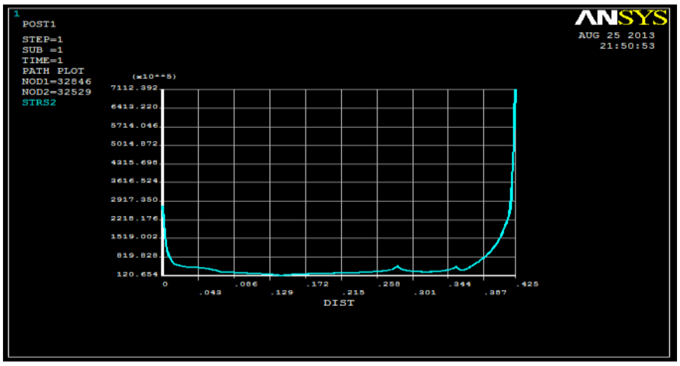

Fig 28: Thermal stress along the symmetry diagonal of the composite cast-mold combination

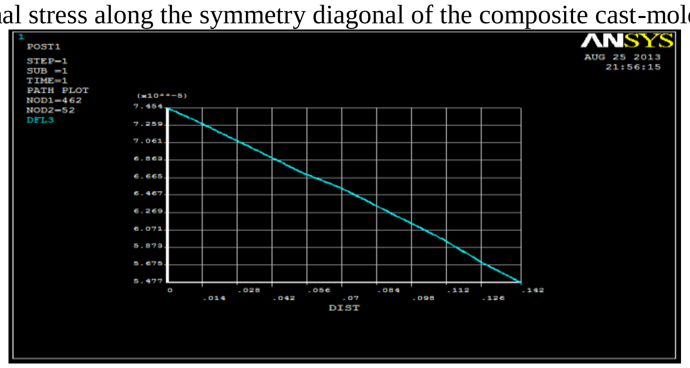

Fig 29: Shrinkage along symmetry diagonal of cast part of composite cast-mold combination

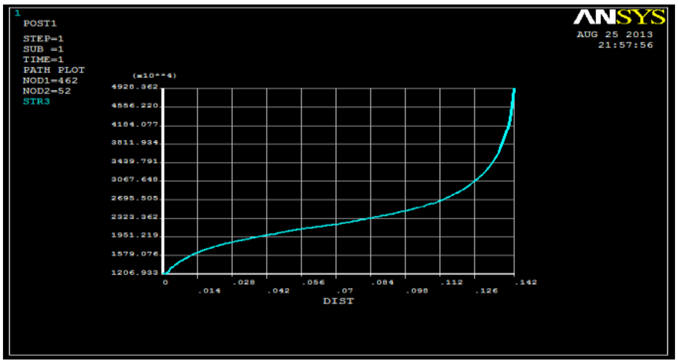

Fig 30: Thermal stress along the symmetry diagonal of cast part of the composite cast-mold

Now from the above graph we can tabulate the following result data with reference of the symmetry diagonal.

Table 6.1: Results of couple field analysis

Mold type	Whole mold cast assembly		Only Cast Part	
	Maximum Shrinkage	Maximum Thermal Stress	Maximum Shrinkage	Maximum Thermal Stress
Sand Mold	0.1091 mm	1169 MPa	0.1091 mm	43.74 MPa
Mullite Mold	0.1415 mm	605.6 MPa	0.1151 mm	89.97 MPa
Sand-Mullite Composite mold	0.07699 mm	711 MPa	0.07454 mm	49.28 MPa

From the above data it is quite evident that in sand mold cast object experience less thermal stress but than mullite and composite mold but the shrinkage on the casing is least in composite mold. So it may be concluded here the composite mold is most suitable for casting an object with pure iron.

VII. CONCLUSIONS

From the present work it can be concluded that, if it is possible to predict different output result from a casting process prior to the actual casting process then it becomes very useful to take decision on the different casting parameters for better cast product. As it has been mentioned earlier that if by any means it is possible to predict temperature distribution and thermal stress after solidification of cast object in a mold then casting defects may kept as minimum as possible.

In the present work it has been shown that FEA software like ANSYS may play an important role in this regard. Transient thermal analysis and Couple-Field analysis in ANSYS can predict temperature distribution and thermal stress distribution in the casting after solidification very accurately. This fact has been proved by validating a transient thermal analysis which has been published in a reputed journal. After validating the thermal analysis, work has been extended to Couple-Field Analysis for thermal stress.

On the basis of thermal analysis result and couple-field analysis result, work may be extended for determination of optimum mold layer thickness and best material for mold making or best combination of mold material with optimum thickness combination.

In chapter six few modifications have been simulated and tested whether they are better than the configuration considered in the base paper. As first modification sand has been replaced by mullite and it has been seen that the mold shrinkage is less but the cast shrinkage is more. Thermal stress in the mullite mold is less than the sand mold. For the sand-mullite composite mold shrinkage is least as well as shrinkage for the cast is also least. But the thermal stress is more than the mullite mold. So optimization can be done as a future work for best combination of mold materials in a composite mold with optimum thicknesses.

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