Simulation of Polymer quenching Process on medium Carbon steel for different concentration of ethylene glycol

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Abstract— Simulation of Quenching Process of steel in CFD is one of the method to plot temperature profile and calculate HTC at surface of specimen. Quenching of medium carbon steel with various quenching medium is done using CFD tools. Quenching medium is varied by varying concentration of ethylene glycol by mass in its aqueous solution form 0% to 60%. Temperature plots at different concentration and cooling curves at core and surface of specimen at different concentration were presented in this work.

Keywords— Polymer quenching, cooling curve, modelling, meshing, outer domain, solid domain, temperature plot, ethylene glycol concentration.

INTRODUCTION

Quenching is performed to prevent ferrite or pearlite and allow martensite formation. Section size and shape of work piece also affect the quenching process. When work piece of large section size is quenched the surface cools more rapidly and hence fully hardened, whereas core cools more slowly and form soft structure variation in section size and shape will lead to different cooling rate and that will influence the cooling rate require for hardening. The percentage of martensite increase from core to surface during quenching of medium carbon steel due to different cooling rate. Peter Fernandez and K. Narayan Prabhu perform quenching process on cylinders of medium carbon steels with diameter 28 mm and 44 mm for different quenchants viz. water, Brine solution, Palm oil and mineral oil. They also perform quenching process with agitation and without agitation. They found that maximum heat flux is more for quenching with agitation. Nucleate boiling stage is delayed in 44 mm diameter specimen compare to 28 mm diameter specimen.

Quenching is performed to prevent ferrite or perlite formation and allow martensite formation. When work piece of large section size is quenched, the surface cooled more rapidly and fully hardened whereas core cools more slowly and formed soft structure. Variation in section size and shape will lead to different cooling rate and influence hardening of material. The percentage of martensite increased from core to surface during quenching of medium carbon steel due to different cooling rate.

Significant amount of residual stresses can be developed during water quenching. The high residual stresses can result in sever distortion of the component and can even cause cracking during quenching. During quenching heat is transfer from surface of component to quenching medium and from core of the component to surface. Heat transfer to quenching medium is more rapid compare to heat transfer within component due to this temperature gradient is developed across the section of the component. This is responsible for uneven contraction of surface and core. This phenomenon leads to development of residual stresses within component. Heat transfer quenching undergoes three main stages namely vapor blanket, nucleate boiling and convective cooling. The highest heat transfer co-efficient are observed in nucleate boiling stage. They also observed that agitation enhances the heat transfer process.

In present work we are going to simulate the quenching process of medium carbon steel for different quenching medium. From this simulation we can get temperature at surface as well as core. We can obtained cooling curve for different location and by comparing it with critical cooling curve. We can find out location where martensite formation is less. Also we are going to find effect of change of concentration of ethylene glycol on heat transfer coefficient of surface of component. In our simulation variation of thermal properties of component and quenchant is taken into account which gives more satisfactory simulation.

MATHEMATICAL MODELLING

Present work focused on simulation of quenching process of EN09 rollers for different quenching medium. Quenching medium includes water & ethylene glycol aqueous solution for different concentration. Objective of this work is to obtain temperature at different interval of time at different location to plot cooling curve for different quenching medium. Also we are going to obtain HTC for different medium interaction and effect of concentration of ethylene glycol on HTC. Temperature difference between core and surface of specimen can also be obtain from simulation which is useful for prediction of residual stress formation.

ASSUMPTIONS

Material of specimen as well as fluid for medium are considered homogeneous. Properties of fluid changes with respect to temperature. Latent heat of phase change solid – solid of specimen material is neglected as it has very minor significance considering the whole process. Domain boundaries are considered to be continuously expanding and hence heating of medium due to boundary is neglected. Initially fluid is considered at zero velocity i.e. no convection at start of trial. No agitation is provided to specimen. Temperature at start of trial is uniform for liquid as well as for solid specimen.

MATERIAL SELECTION

We are conducting experiment on EN09 steel which is medium carbon steel. The work piece is of cylindrical size of length 0.1m and diameter 0.05m.
Material Composition

Carbon C	0.47-0.55%
Iron fe	Remaining
Manganese Mn	0.6-0.9%
Phosphorous P	0.04% Max
Sulphar	0.05% Max

BOUNDARY CONDITION AND BOUNDARY INTERFACE

Solid specimen boundary conditions:
At t =0 sec, $T_s = 1173$ k for $0 \leq r \leq r_c$, $0 \leq l \leq l_s$
Quenching medium initial temperature: 298k
Fluid domain size: 4m X 4m X 4m
Fluid domain Boundary Condition: $T_m = 298$k, P = 1.013 bar

MODELLING

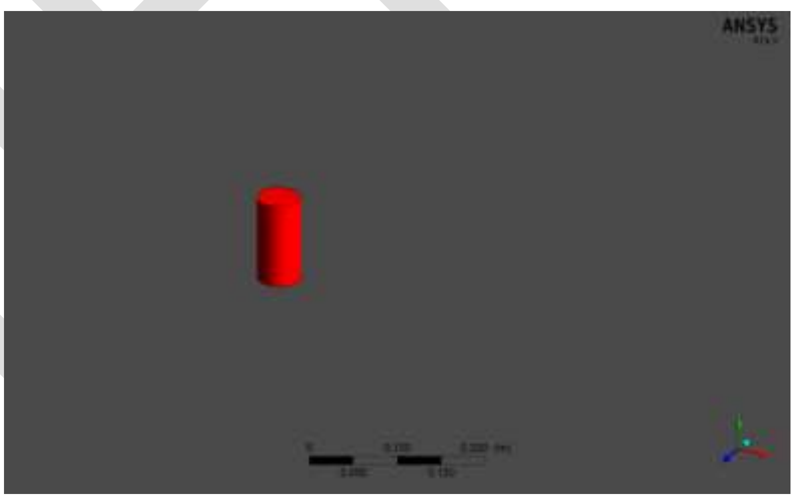

Fig: 3D Model of Solid Specimen.

The model is cylindrical roller with diameter 0.05m and length 0.1m.

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MESHING

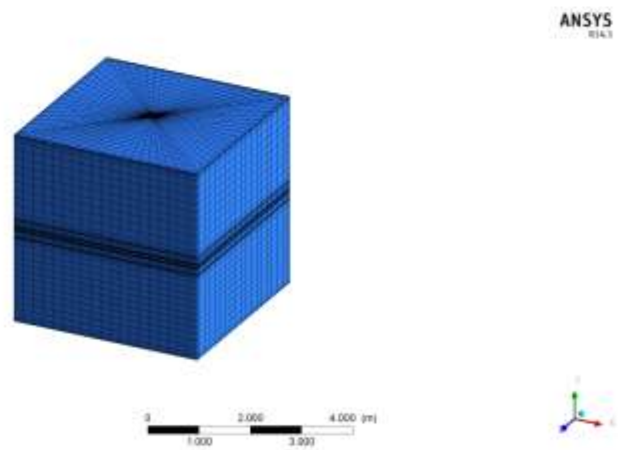

Fig: Meshing of Outer Domain

The above outer domain model shows the meshing using hexahedron elements and structured type of mesh.

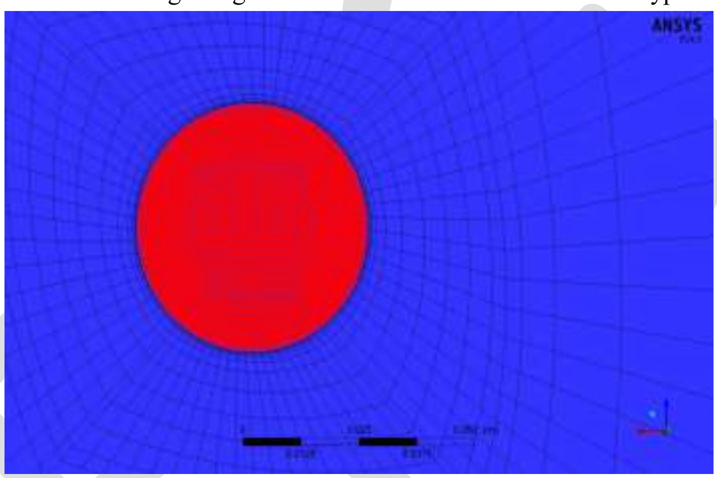

Fig: Top view of solid domain

The above solid domain model shows the meshing using hexahedron elements and structured type of mesh. Above model also shows that meshing of fluid domain near solid domain is finer due to requirement of more accuracy and mesh size goes on increasing as we move away from solid domain.

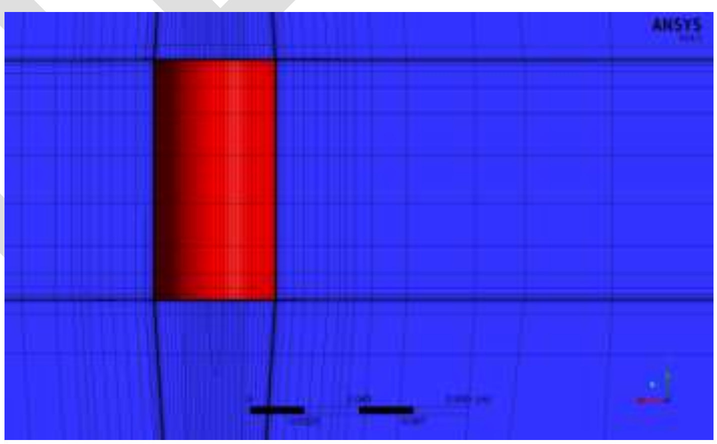

Fig: Side View of Solid Domain

The above solid domain model shows the meshing using hexahedron elements and structured type of mesh. Above model also shows that meshing of fluid domain near solid domain is finer due to requirement of more accuracy and mesh size goes on increasing as we move away from solid domain.

RESULT AND DISCUSSION

The thermal performance is analysed for work piece to be quenched. Different trials are taken by varying quenching medium with increasing concentration of ethylene glycol by mass.

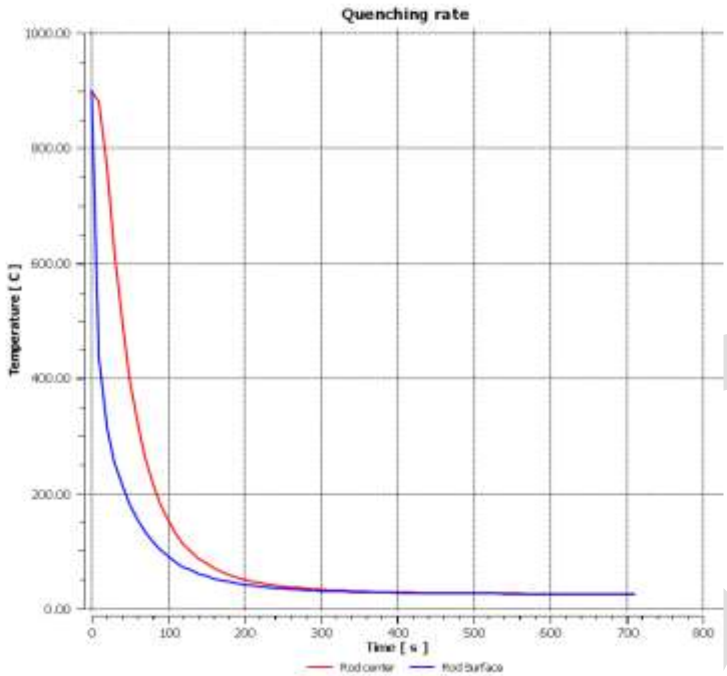

Fig: Temperature Vs Time for 0% concentration by mass of ethylene glycol

The above graph shows variation of temperature with respect to time for surface and core. Large temperature difference between surface and core of the specimen is observed. Due to variation in cooling of surface and core there will be uneven contraction of material of specimen which is responsible for residual stresses.

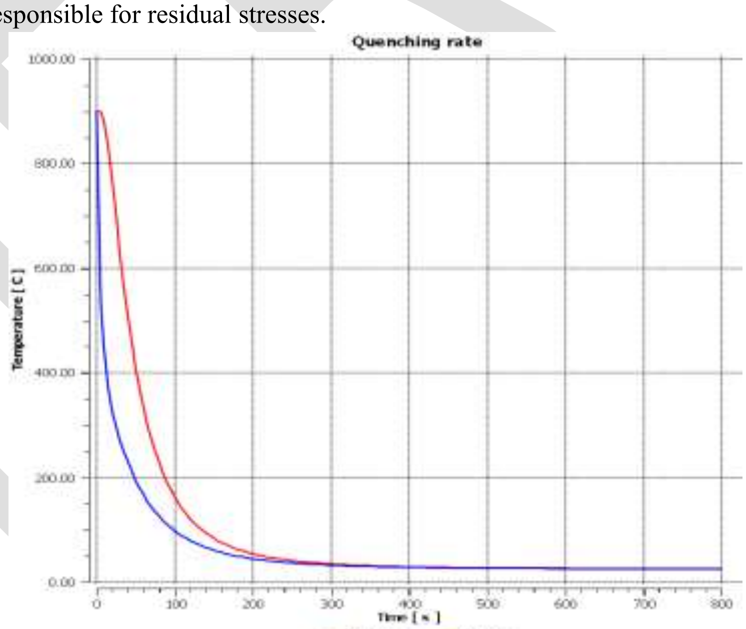

Fig: Temperature Vs Time for 20% concentration by mass of ethylene glycol

The above graph shows variation of temperature with respect to time for surface and core when quenching medium is 20% ethylene glycol solution by mass. The temperature variation between surface and specimen at particular instant is less compare to previous quenching medium which leads to less residual stress formation compare to previous trial.

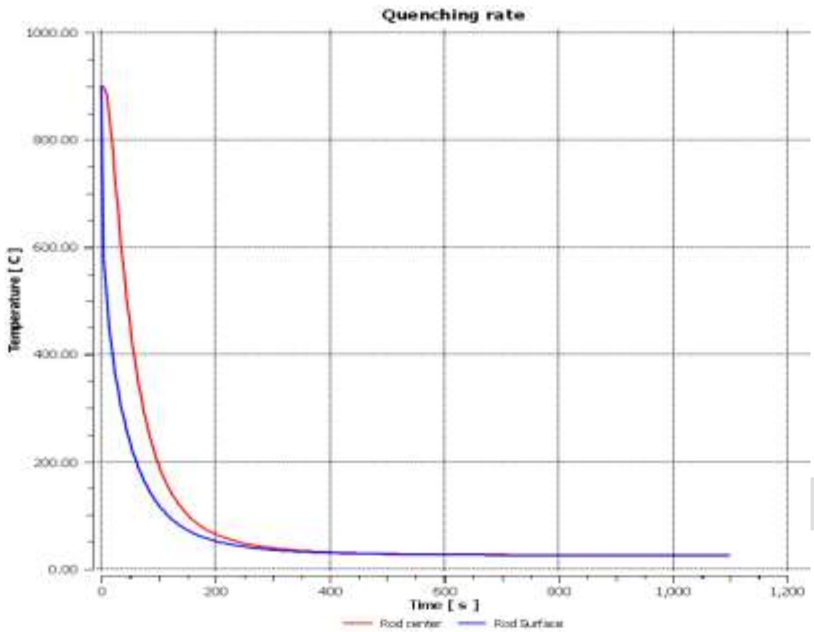

Fig: Temperature Vs Time for 40% concentration by mass of ethylene glycol

The above graph shows variation of temperature with respect to time for surface and core when quenching medium is 40% ethylene glycol solution by mass. Temperature difference between surface and core of the specimen decreases further for this trial. We can predict that residual stress formation for this trial reduces further.

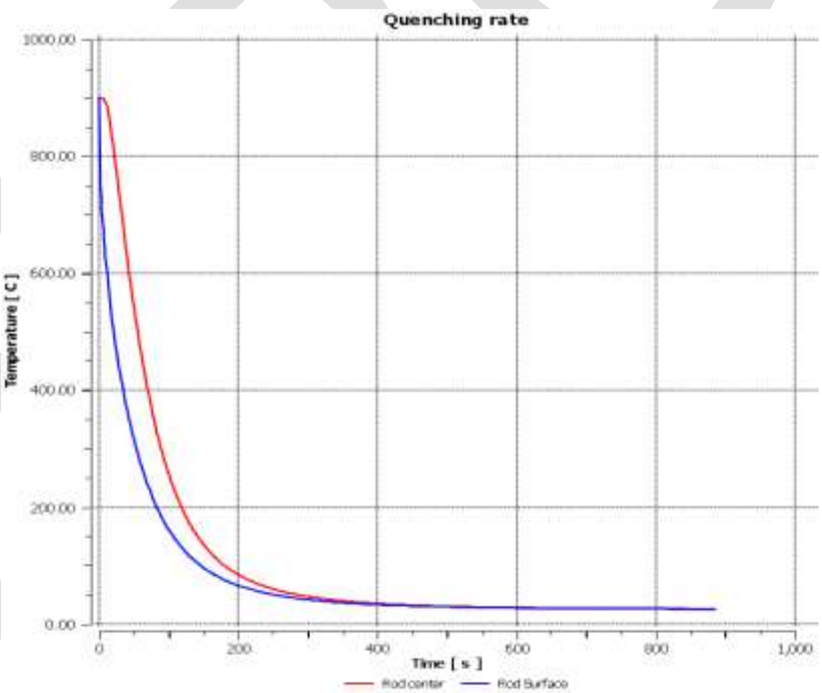

Fig: Temperature Vs Time for 60% concentration by mass of ethylene glycol

The above graph shows variation of temperature with respect to time for surface and core when quenching medium is 60% ethylene glycol solution by mass. The cooling rate is slowest for this trial. As percentage of ethylene glycol increases in aqueous solution rate of heat transfer from surface to quenching medium decreases. Heat transfer by convection approaches the heat transfer by conduction within specimen and hence temperature gradient between surface and core of specimen is least for this trial. It is predicted that residual stress formation is least for this trial. As percentage of ethylene glycol increases in quenching medium the temperature gradient goes on decreases and it will result in less residual stress formation.

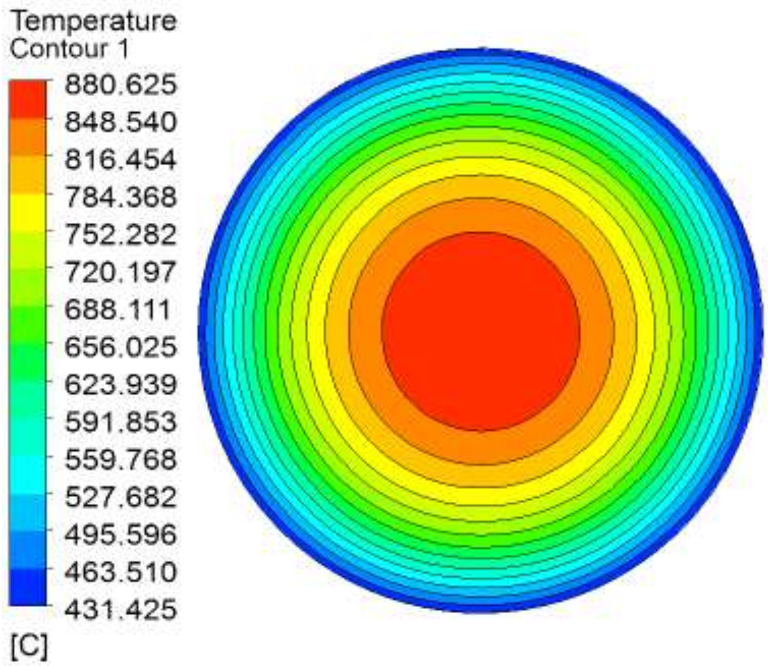

Fig: Horizontal temperature plot after 10 sec during trial when ethylene glycol concentration is 0%.

Above plot shows temperature distribution along horizontal section after 10 sec when quenching medium contains 0% ethylene glycol. It shows that after 10 sec core is at 880.6250C and surface is at 431.4250C.

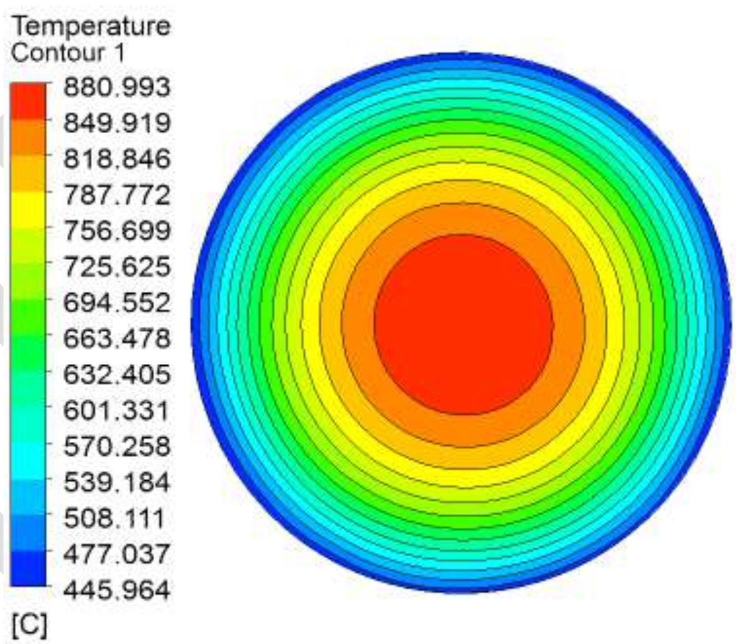

Fig: Horizontal temperature plot after 10 sec during trial when ethylene glycol concentration is 20%.

Above plot shows temperature distribution along horizontal section after 10 sec when quenching medium contains 20% ethylene glycol by mass. It shows that after 10 sec core is at 880.9930C and surface is at 445.9640C.

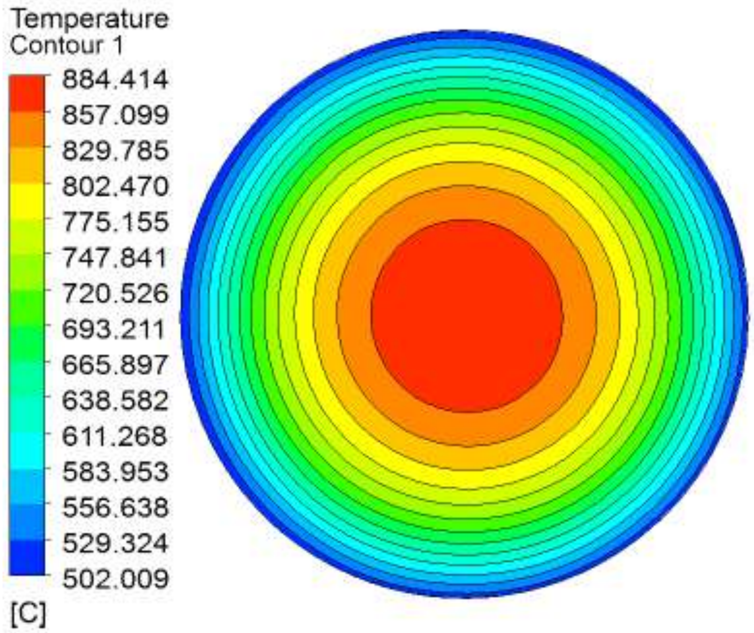

Fig: Horizontal temperature plot after 10 sec during trial when ethylene glycol concentration is 40%.

Above plot shows temperature distribution along horizontal section after 10 sec when quenching medium contains 40% ethylene glycol by mass. It shows that after 10 sec core is at 884.4140C and surface is at 502.0090C.

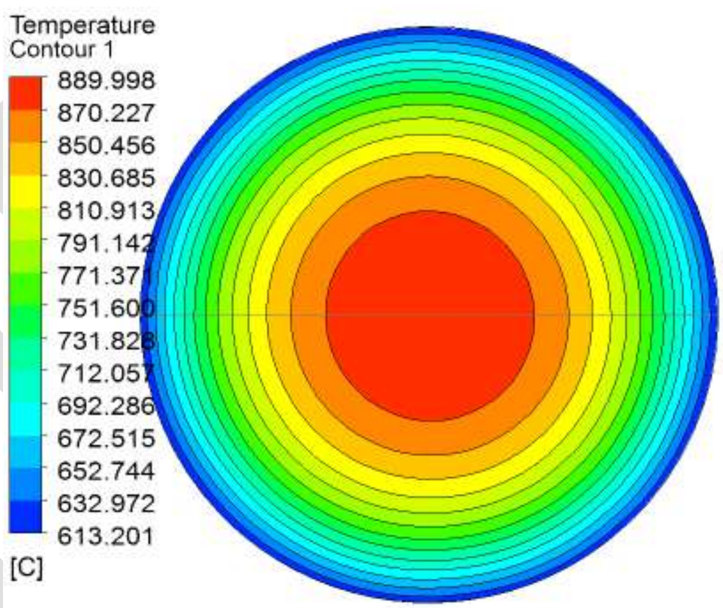

Fig: Horizontal temperature plot after 10 sec during trial when ethylene glycol concentration is 60%.

Above plot shows temperature distribution along horizontal section after 10 sec when quenching medium contains 40% ethylene glycol by mass. It shows that after 10 sec core is at 889.9980C and surface is at 613.2010C.

Above plots shows the temperature distribution of specimen on horizontal plane after 10 sec. We can observe that as concentration of ethylene glycol increases the temperature gradient decreases. So we can predict that residual stresses induced will decreases as concentration of ethylene glycol increases.

CONCLUSION

Based on results and conclusion following conclusions were drawn:

1. With increase in concentration of ethylene glycol by mass cooling rate of specimen during quenching process decreases.
2. With increase in concentration of ethylene glycol by mass temperature difference between core and surface of specimen decreases.
3. Increase in concentration of ethylene glycol in its aqueous solution can be useful to reduce temperature gradient induced during quenching process which is responsible for residual stress formation.

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