To Study the Heat Transfer Characteristics of AISI 1045 Steel Component for Quenching Process

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Abstract: Automotive components are Heat Treated and Quenched to achieve desirable mechanical properties and it is physical process, which consists of various parameters interaction. A quench factor (Q), has been showed that the overall severity of the steel hardening process—quench severity by relating steel hardenability with the quenching variables including: the different quenchant being used, temperature etc. Successful hardening depends on the hardness of the steel composition, geometry of the component, quenching system and on the heat treating process used. The heat-transfer coefficient has a significant effect on the properties of the final product, like hardness, strength, residual internal stress etc. Therefor to analyzed Heat Transfer coefficient, quench factor analysis and its effect on the Hardness of the element. This paper will describe the use of cooling curve, quench factor analysis to successfully predict as quench hardness of AISI 1045 steel.

Keywords: Heat Transfer Coefficient, Hardness, Quenching ,Quench factor.

1. Introduction

Heat treatment process is a multiparameters, dynamic in nature. The selection of appropriate parameters predicts required behaviors of heat treated components. The different type of quenchents medium, the selection of quenchents medium temperature and the selection of the medium state such as unagitated, agitated are determining factors [1]. In the industry of metal shaping & forming processes, heat generation occurs due to plastic deformation energy. In the process of heat generation and heat transfer from material to active tool mainly influences the service life of the tool. The major factors effecting life of tool in the elevated temperature forging processes are worn, heat checking, fatigue, and plastic deformation. The different types of products formed during cooling contribute to the overall formation of transformational stresses. The cooling rate is also vitally important because it contributes to the formation of thermal stresses. Taken together, the combination of the thermal and transformation stresses is a controlling factor involved in the resulting hardness distribution, distortion and cracking potential of steel [6].

The quenching process is a transient heat-transfer problem, and the temperature difference between the workpiece and the quenching medium cannot be directly adjusted to control the boundary heat flux. The only way to mainly affect the quenching process is to adjust the heat-transfer coefficient [7]. Improved quenching practices permit the use of less hardenable, less expensive steel to achieve the desired properties. The examination of quenching performance by cooling curve analysis is becoming increasingly popular and perhaps the most informative method of characterization a quenchents. The cooling curve produced when component initially at temperature above the boiling point of quenchents, is introduced into the liquid, is much more complicated than derived by Newton's law of cooling , heat transfer is controlled by different cooling mechanism as shown in fig 1.

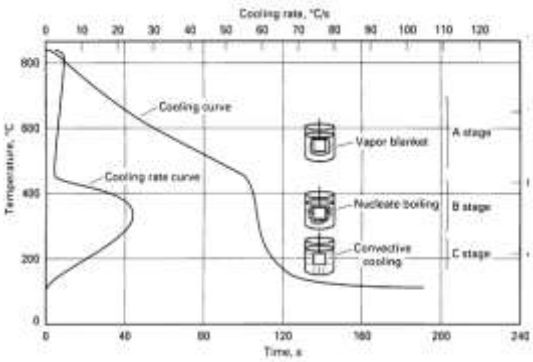

Fig1. Cooling curve and cooling rate curve at the centre of a 25 mm diameter probe quenched [5].

Quench factor Analysis:

The quench factor analysis is based on the Avrami or "Additivity" rule. Scheil first suggested the additivity rule to describe incubation or nucleation during phase transformation [11]. Avrami continued this analysis and showed that, the additivity rule is applicable only, when the nucleation rate is proportional to the growth rate. Avrami developed different types of expression to describe the rate of transformation during phase changes depending upon whether there are less or many nuclei present and upon the type of phase growth that occurs. Transformation-rate laws were derived for transformations where nucleate on grain boundary surfaces, grain edges, and grain corners.[11] There is a inverse relationship between the quench factor (Q) that is obtained with both hardness and strength. Generally hardness and strength increases as the numerical value of the quench factor decreases. The critical value of the quench factor, Q, will result in the desired hardness or strength and this value can be defined in terms of the maximum allowable amount of transformation during cooling process.
Quench factors are calculated from digital time-temperature (cooling curve) data and a *CT* function

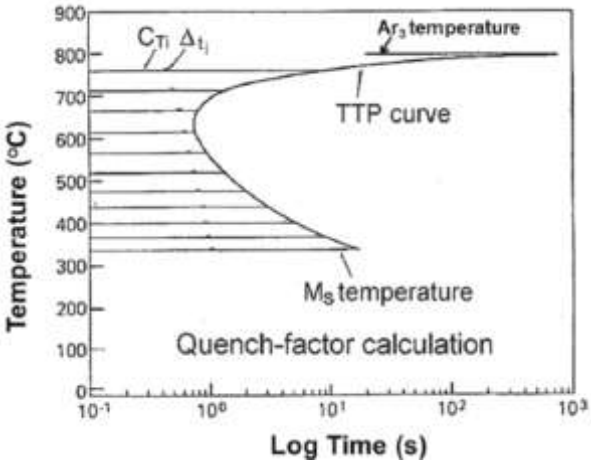

Fig2. Method for calculating a quench factor which relates the cooling time- temperature exhibited by quenching being analyzed by TTP curve for steel alloy.

An incremental quench factor, *q*, for each time step
in the cooling curve, is calculated from
$\frac{\Delta t}{Ct}=q$
Where, Ct= Time function & Δt= Time Step

II. EXPERIMENT SET UP

The cylindrical bar was used for computing surface heat flux in a 25 mm diameter and 100 mm long cylindrical plain carbon steel (1045 grade) specimen during quenching in a different quenchents such as oil, polymer solution & water.
Prepare sample from long 1045 steel bar. Total 4 no. of sample where prepared in workshop. The fig 3 shows the details of specimen.

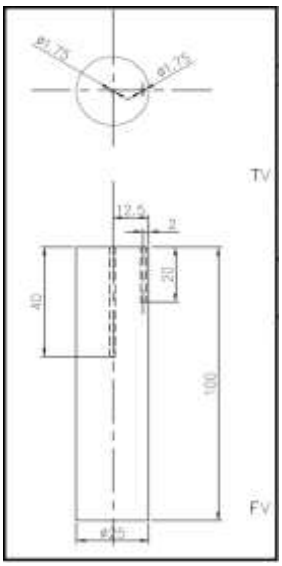

Fig3. Specimen of 25mmX100mm of steel 1045 grade used for testing purpose

A schematic of the test components are shown in Fig. 3. The experimental setup has two parts: (i) A hand held portable thermocouple unit for measuring the temperature of the specimen during quenching and (ii) Electric resistance furnace for heating the specimen The hand held unit comprised of a solid handle which attached to a stem manufactured, the specimen made of the specific grade of steel being quenched (in this case, 1045 grade steel) could be fixed at the end surface of the rod, a 'K' type insulated, stainless steel coated thermocouple fixed at a radial distance of 2 mm form the surface of the specimen, a mechanical system for ensuring contact of the thermocouple with the specimen and a data acquisition system. Three thermocouple used in the experiment. One at core, another at surface from dist. of 2mm from surface and third one in the furnace. The core thermocouple is inserted at depth of 40mm, while at surface thermocouple at depth of 20mm.

Once the specimen was heated to the desired temperature of 860°C and soaked for 10 minutes, the hand held unit was removed from the furnace and the specimen quickly immersed into the quenchents. The temperature was recorded at every one second interval during quenching. The different quenching media used oil , water and polymer solution. Note down the reading for different experimental conditions. The Time Temperature data is recorded on I –Tool instrument.

Different quenchents type and different quenchants temperatures were used to determine the effect of the type and the temperature on the results, table 1 shows the testing conditions during the experimental work. Fig.2 shows the actual specimens are ready for experiment.

Table1. Testing conditions during the experimental work.

S. No	Quenchants	Condition
1	Oil (Meta quench-43)	Flash point 160°C
2	Water (Tap Water)	At 30°C
3	Polymer(Polydor-C 15%)	At 55°C

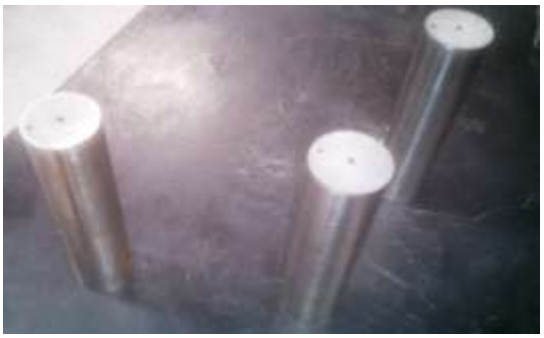

Fig4. Specimen ready for experiment.. No. of specimen are Three.

III. RESULTS AND DISCUSSION

In given experimental procedure work piece (AISI1045) was selected and heated up to 860ºC temperature and then will be placed in quenching tank for Heat treatment process. During this operation measure the Temperature with help of thermocouple etc.

1) Calculation of Cooling Rates and HTC for different quenchents media

Cooling curve is used to calculate the cooling rate and heat transfer coefficient is function of surface temperature. Used in simple way, the HTC by functional dependent on temperature, it can be used as boundary condition in simulation of cooling processes.

The following different graphs are derived from cooling rate formula at surface and core. The Heat Transfer coefficient is calculated from cooling curve with help of Kabasco's formula.

1) For Oil as quenchant

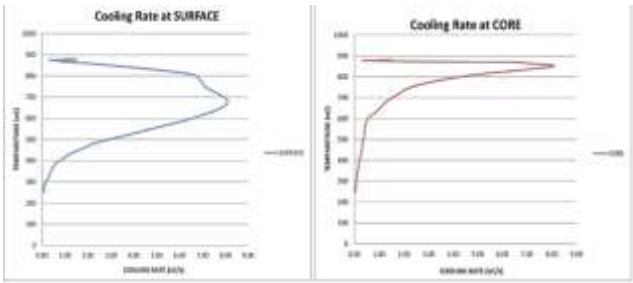

Fig5. Cooling Rate for Oil (At surface and core).

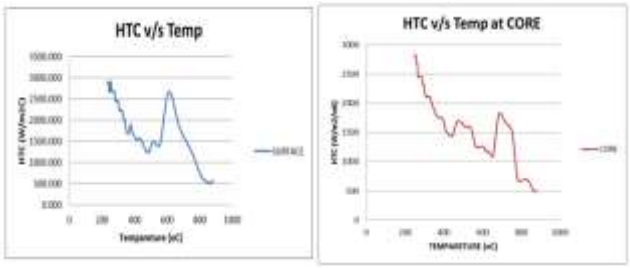

Fig6. Heat Transfer Coefficient v/s Temp. for Oil (At surface and core).

2) For Polymer as quenchant

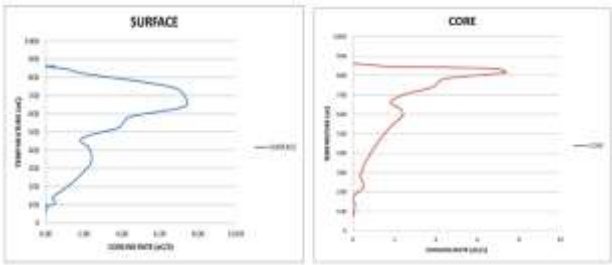

Fig7. Cooling Rate for Polymer (At surface and core).

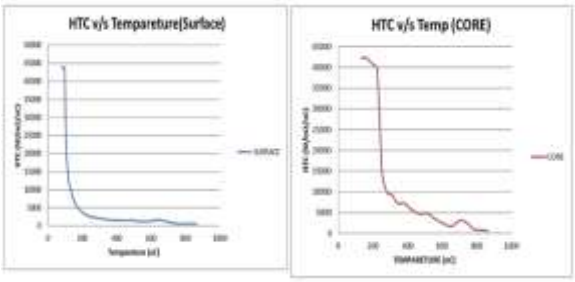

Fig8. HTC v/s Temp. for Polymer (At surface and core).

3) For Water as quenchant

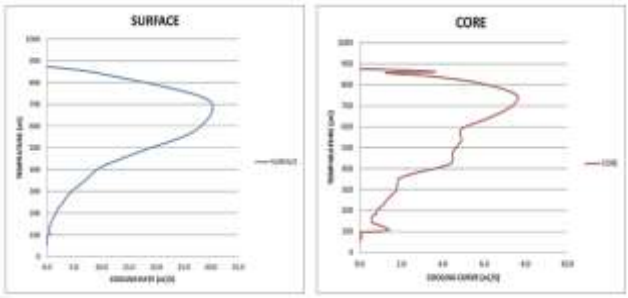

Fig9. Cooling Rate for water (At surface and core).

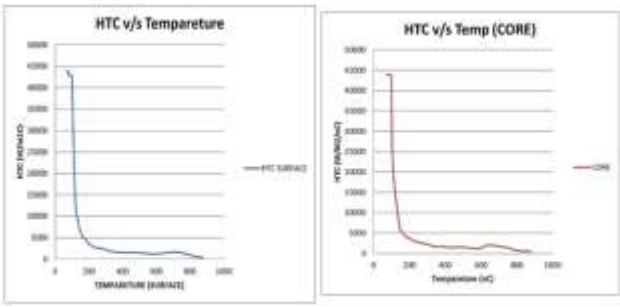

Fig10. HTC v/s Tempareture for water (At surface and core).

Fig. 5 to 10 shows all cooling curve and HTC curve for steel together for different quenchants. Figure also shows the derived cooling curve for all medium quenchents for steel used together with HTC; the essential characteristic of these curve are similar, especially in range of 600°C to 850°C.

The quench factor analysis shows that, there is a reciprocal relationship between the quench factor (Q) that is obtained with hardness. Generally the hardness increases as the numerical value of the quench factor decreases. The critical value is the maximum value critical value is the of the quench factor (Q), that will result in the desired hardness and this value can be defined in terms of the maximum allowable amount of transformation during cooling.

Table 2, provides an illustration of the reciprocal relationship between as-quenched hardness and the value of Q for AISI 1045 for three different quenching medium

Table 2 Relationship between Quench factor and Hardness

Sr. No	Quenchant	Quench Factor	Hardness (HRC)	
			Predicted	**Actual**
1	Oil	39.4	52.9	53.4
2	Polymer	30.2	54.5	55.2
3	Water	28.3	58.9	59.2

The quench factor analysis is depend upon time function Ct (Ct = It defined as the critical time required to form a constant amount of a new phase or reduce the hardness by a specified amount) and incremental quench factor (q). As experimental reading of hardness variation checked. The following results are obtained. Hardness value is obtained from surface to core

1) **For Oil Quenching**

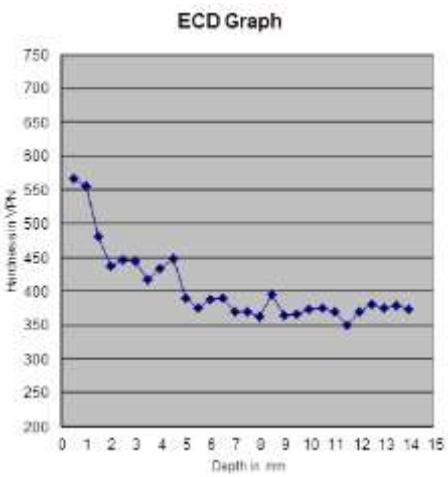

Fig11(a). Hardness variation along depth of Specimen radially.(Oil)

For Polymer Quenching

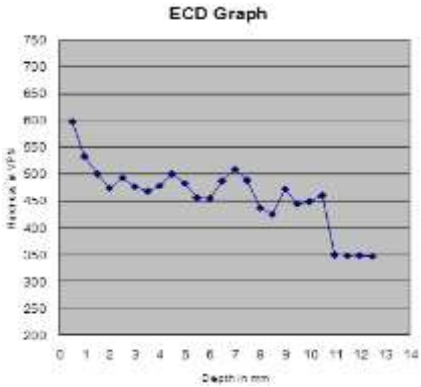

Fig11(b). Hardness variation along depth of Specimen radially.(Polymer)

2) For Water Quenching

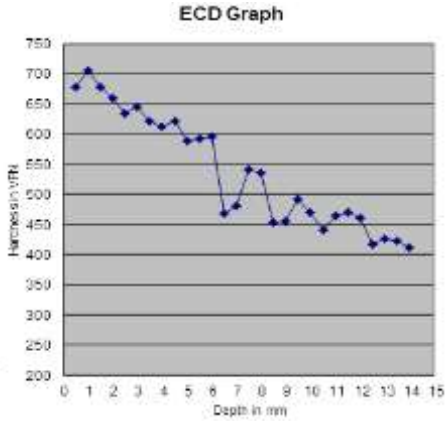

Fig11(c). Hardness variation along depth of Specimen radially.(Water)

3) For Soft Material (AISI 1045) without Quenching

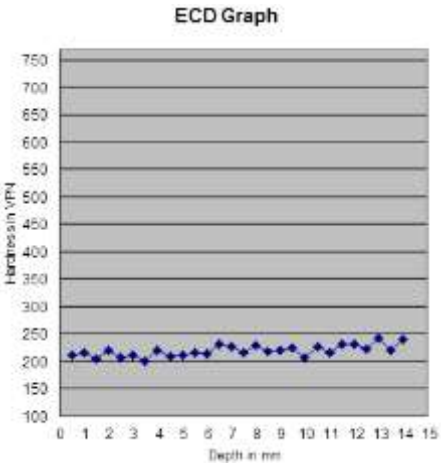

Fig11(d). Hardness variation along depth of Specimen radially (Without Quenching)

From figure 11(A) to 11(C), its shows that, the hardness is continuously varying from surface to core. In case of oil and polymer quenching the variation is slow but compare with water quenching the hardness varying rapidly. For different hardness reading at surface and core of specimen AISI 1045 is given in Table no. 3

Table 3. . Different Hardness value for different quenching medium for surface and core of specimen AISI 1045

Sr. No	Quenchant	Hardness (HRC)	
		Surface	**Core**
1	Oil	53.4	36.5
2	Polymer	55.2	38.2
3	Water	59.2	42.5

4	Soft	13.5	15.2

IV. CONCLUSIONS

The Different types of experimental and mathematical investigations show that the heat-transfer coefficient (HTC) during the industrial quenching processes has a considerable influence on the resulting component AISI 1045 properties such as the hardness distribution. The cooling curve analysis of three quenching medium shows ability & severity of quenching media. The water has maximum hardness (59.2 HRC) as compare to other two media & is 10% more.

The HTC value for water medium is high 4385 W/m²/°C as compare to oil 2980 W/m²/°C. It shows that high rate of transition of phase & rapid cooling leads to harden the material. The calculated cooling graph curve and time-temperature curve when combine with heat transfer coefficient and the quench factor method gives the estimation of hardness variation as function of distance. With the help of quench factor analysis successful predication of as quenched hardness is done.

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