Experimental Investigation of effect of Jet Impingiment Dual Quenching process on Mechanical properties of AISI D2 steel

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Abstract— **AISI D2 steel (HCHCR) is a high carbon high chromium steel with range of industrial application. . Due to high carbon content die steel have excellent hardness and moderate toughness. Improvement of toughness while hardening is a challenging problem. Heat transfer enhancement is one the major parameters required to improve the performance of the thermal systems in many industries such as electronics, aerospace, automotive and steel manufacturing. Jet impingement cooling and spray impingement cooling are two of the most effective ways to improve the rate of heat transfer from the hot metal surface. Impingement cooling helps to achieve desired cooling rates from the surface by appropriate parametric control during the cooling process. Hence this process finds its use in many application in particular to metal processing industry . The main focus of the present work is to study experimentally the mechanism of jet impingement cooling in single and double quenching and the effect of mechanical are compared with conventional method of quenching . Numerical analysis of jet impingement cooling is conducted to optimize the parameters like the ratio (H/d) of the jet to target spacing (H) to the jet diameter (d). Parameters effecting jet impingement cooling are H/d ratio, jet velocity ,single jet ,multiple jet . The distance between nozzle exit to impinging surface (H/d) is varied from 2 to 7 and found the optimum H/d as 6 the result is experimentally validated The effects of parameters were studied at this optimum nozzle-to-plate distance. Mechanical property tests like charpy, brinnel and Rockwell test were carried out to study the effects of jet impingement and double quenching processes on hardness and toughness. From the results it was found that the toughness value almost doubled in case of jet impingement double quenching process. Jet impingement process also show improvement in hardness over conventional quenching. Microstructure study shows that the grains of jet impingement double quenching is finer when compared to conventional means. As the grain boundaries increases it inhibits the crack propagation result in improving toughness.**

Keywords— **jet impingement, double quenching, heat treatments**

I. Introduction

AISI D2 steel is a high carbon; high chromium steel alloyed with vanadium and molybdenum characterized by high wear resistance, high compressive strength and moderate toughness. Due to high wear resistance and moderate toughness is used as die in many of the punching application and also for tool. The materiel is hardened by various heat treatment process. The main issues facing while hardening is that it imparts more stress on material effect is the decrease in toughness. Increasing toughness while hardening is a challenging problem.

Jet impingement cooling is an attractive cooling mechanism of achieving high heat transfer rates. It provides an effective means of removing localized heat loads. Jet impingement is one of the most efficient solutions of cooling hot objects in industrial processes as it produces a very high heat transfer rate of forced convection. A characteristic feature of this flow arrangement is an intensive heat transfer rate between the wall and the fluid. This cooling method has been used in wide range of industrial applications such as annealing of metals, cooling in grinding process, electronic cooling, cooling of gas turbine blades etc.

The impinging jet flow problem has been found to provide a good test ground for CFD codes and models. Using CFD, the parameters of jet impingement cooling can be optimized. The purpose of heat treatment is to change the grain size, to modify the structure of the material and to relieve the stress develop in the material after hot and cold working. Steel is one of the most widely used materials in today's industries.

Double quenching is a dual quenching process in which a specimen is subjected to two complete hardening operations. conducted at the same temperature. The mechanical properties of low alloy steels can be improved by austenite grain refinement.

M.H. KhaniSaniji[1] had conducted studies evaluate the effect of double quenching and tempering (DQT) with conventional quenching and tempering (CQT) heat treatment processes on microstructure and mechanical behavior of a commercially developed hot rolled AISI 4140 type steel. BožoSmoljan[2] investigated the strengthening of AISI 4140 steel by cyclic heat treatment. Khamaal Muhsen Kseer [3]studied the effect of double quenching heat treatment on microstructure and dry sliding wear behavior of low carbon dual phase steel with carbon concentration (0.0977% C) was investigated. K. Patrick [4] also studied the effect of the tempering temperature on the hardness. Procter R.P.M [5]had conducted experiments using both conventional heat-treatments and repeated rapid austenitising and quenching heat-treatments and the results show considerable improvements in wear resistance.Li Chang-geng[6] had conducted an experimental and numerical simulation study of heat transfer due to a confined impinging circular jet Chitranjan Agarwal[7] explored the effect of jet exit to surface spacing on the cooling of stainless steel surface of 800^{o}C temperature.

II. NUMERICAL ANALYSIS.

Jet impingement heat transfer is a function of many parameters: Reynolds number(Re), the ratio of axial distance from nozzle exit to impingement plate over diameter (H/d).In addition to these ,the effect of nozzle geometry ,flow confinement, turbulence effect the heat transfer coefficient. In this numerical study only the effect of H/d is considered. A computational study was performed for optimizing H/d ratio by validating the result with experimental values. The work was carried out using a commercial software package which is standard Finite Volume Method

A. Computational Domain

The flow is assumed to be steady incompressible, so pressure based solver is used for the numerical analysis. The SIMPLE (Semi-Implicit Method for Pressure-Linked Equations) algorithm is used as the solution method. This algorithm is essentially a guess-and-correct procedure for the calculation of pressure on the staggered grid arrangement. To simplify the analysis, the flow is assumed to be at steady state, the fluid physical properties are constant and the effect of gravity is neglected. For this numerical simulation flow is assumed to be incompressible, turbulent with constant fluid properties. For better heat transfer characteristics, the flow is confined between two parallel plates as shown in fig.1

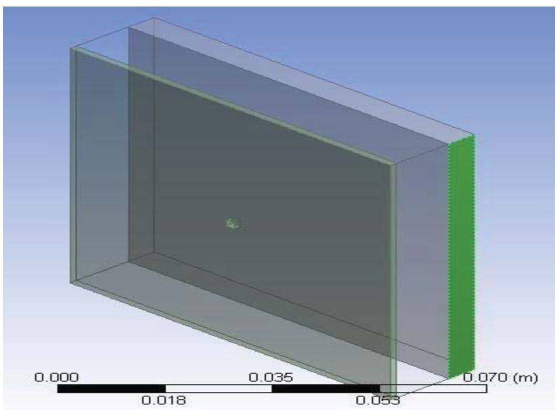

Fig.1 Numerical computational domain

B. Boundary conditions

The three dimensional numerical computational domain consists of three identical velocity inlets, two pressure outlets, target plate and orifice plate with confinements. In the present fluid domain, uniform velocity profile is assigned as the inlet boundary condition. The inlet air having temperature of 300K enters the domain with a Reynolds number of 5000. k-ε turbulent model is used for this numerical analysis.

III. EXPERIMENTAL ANALYSIS

The performance of the jet impingement depends on so many parameters such as jet Reynolds number, nozzle-to-plate distance, inlet jet temperature, type of confinement. The schematic diagram of the experimental set up is shown in fig.2.

A Reciprocating air compressor supplies air to the nozzle. The quantity of air delivered to the nozzle is measured by an orifice meter. The target plate is a square copper block having dimension 74mmx74mmx6mm. The target plate is maintained in such a way that the jets strike the plate orthogonally. The flow of air over the copper plate is controlled by confinement on both sides. Iron blocks are used for the confinement on both sides of the target plate. The air travels through the circular orifices and leaves through the two open ends of the target plate. The temperature distribution over the copper plate is obtained by calibrated copper-constantan thermocouples. Three thermocouples are located at the stagnation points are connected to the temperature scanner. Each data was taken after a steady state condition was reached. The heat conductions through the copper plate in lateral and vertical directions are neglected. Hence the local temperature measured by the thermocouples is considered to be the same temperature of the upper surface of the plate.

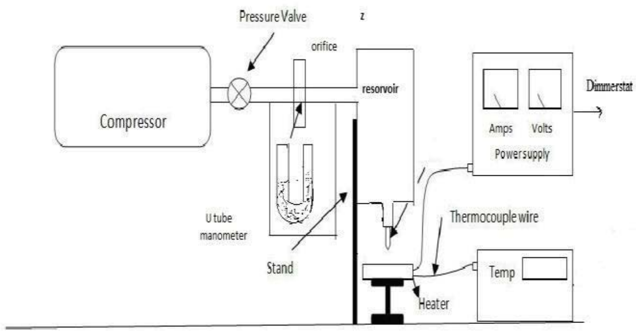

Fig.2 Experimental set up for optimizing H/d

III.EXPERIMENTAL SET UP FOR VARIOUS QUENCHING PROCESS ON AISI D2 STEEL THROUGH JET IMPINGEMENT

Strengthening of steel by cyclic heat treatment consist of grain refinement by temperature cycling with repeated transformation and after that specimen have to be quenched and tempered. For quenching jet impingement cooling is used. Experiment was conducted for the property study of conventional quenching, single quenching and double quenching. Experiment setup is shown in fig. 3.

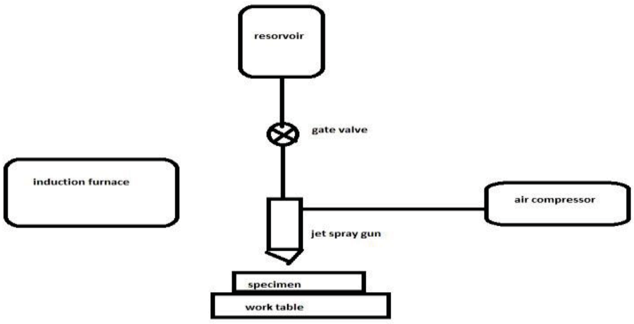

Fig 3.Experimental setup

Experimental setup consist of muffle furnace, air compressor, spray gun, reservoir ,adjustable stand and test specimen .

A. Single jet impingiment quenching

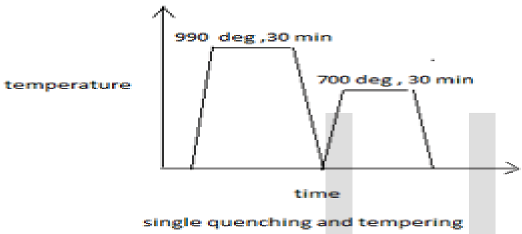

Fig.4 Single Quenching Procedure

Fig.4 shows the single Quenching procedure . Preheat the specimen to 600° C and hold for 30 minutes for homogenization. Increase the temperature to 990° C for austentization and soak it for 30 minutes. After the austentizing ,quench the specimen through jet impingement process. After quenching temper the specimen about 700 °C. Single quenching process ends here.

B. Double jet impingiment quenching

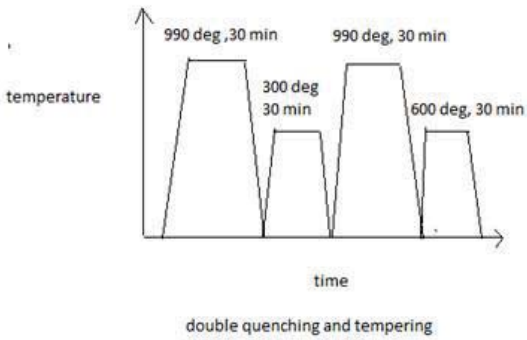

Fig.5 Double Quenching Procedure

Preheat the specimen to 600 ° C and hold for 30 minutes for homogenization. Increase the temperature to 990 ° C for austentization and soak it for 30 minutes. After the austentizing quench the specimen through jet impingement process. After quenching temper the specimen about 300 ° C then heats the specimen as same procedure that we do in first cycle except with the tempering temperature of about 600 ° C

IV. RESULTS AND DISCUSIONS

A. Optimization using CFD

From the graph, fig: 5, for unconfined jet impingement cooling it can be observed that the optimum H/d ratio is 6.

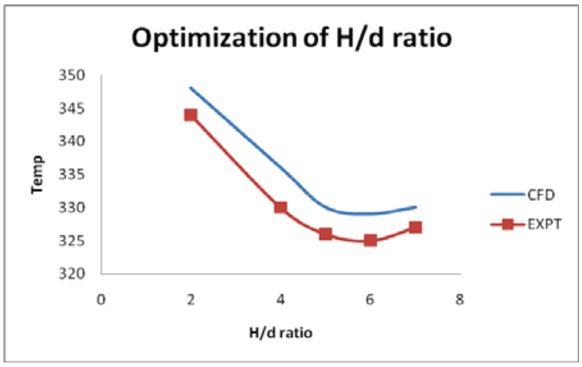

Fig. 6, Temperature distribution for jet impingement cooling by varying the H/d ratio .

In the experiment, the H/d was varied as 1d, 2d, 4d, 6d and 7d while keeping the Reynolds number constant at 5000. The wall temperatures of the target plate including the stagnation point are noted at the steady state condition. The Fig. 6 shows a good agreement of the numerical results with the experimental values. Both the result shows that there is an optimum nozzle-to-plate distance, H/d=6

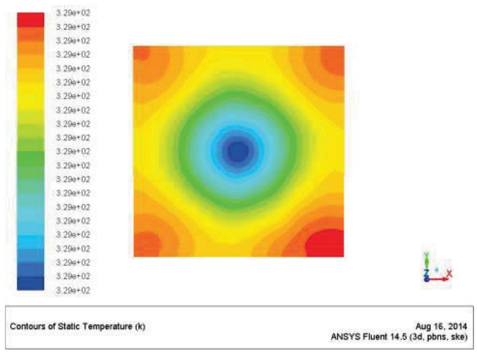

Fig.7 Static temperature distribution of target surface for H/d=6

Fig.7 shows the static temperature distribution of the impingement surface of the target plate. Fig. indicates that the maximum heat transfer takes place at the stagnation point.

A. Rockwell test

Table.1 comparative study on hardness using Rockwell test

Single Quenching	54.5
Double Quenching	52
Conventional Quenching	54

It is found that during double quenching, the hardness decreases, but it is still in the application range that is suitable for most of the application. There is a slight increase in hardness for jet impingement quenching when compared to conventional quenching. The increase in hardness may due to the optimized height which may increase the heat transfer. Absence of vapor blanket in jet impingement is another reason of increasing hardness. From the test parameter it is observed that impinging jet method have a better effect over conventional quenching.

B. Charpy test.

Table.2 comparative study on hardness using Charpy test

Single Quenching	2.5
Double Quenching	4.1
Conventional Quenching	2.3

Results obtained from charpy test emphasis the importance of double quenching and its relevance. The toughness value almost doubled as in the case of double quenching. Increase in toughness may due to the grain refinement. As the grain boundaries increases the chance of crack propagation is less. The grain boundaries inhibit the crack propagation. Which result in improvement of mechanical properties. Jet impingement quenching also shows improvement in toughness when compared to the conventional quenching process.

C. Microstructural analysis

Microstructural analysis is carried out separately for Single quenching , double quenching and conventional quenching. Specimens preparation is an important procedure before analysis. Scratch free surface are obtained after careful specimen polishing. Etchant used is NITAL 3%. Alumina powder is used in machine polishing.

Fig.8,9,10 shows the microstructure analysis of Single ,double and conventional quenching

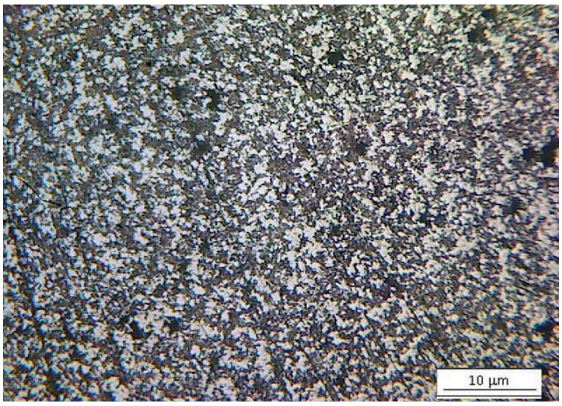

Fig. 8 - microstructure of Single Quenching

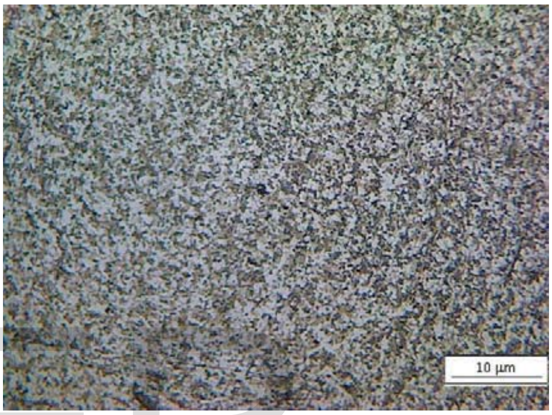

Fig .9 - microstructure of Double Quenching

Fig .10 - microstructure of Conventional Quenching

It is clearly from the structures that the double quenching structure is finer when compared to the other two methods. Effect is due to the recrystallization and also may result in grain refinement. The structures of conventional quenching and single quenching are almost similar. The increase in hardness may due to optimized parameters. The structure fines may be the reason for increase in toughness value and a slight decrease in hardness.

V. CONCLUSION

The improvement of toughness while hardening is a challenging problem in AISI D2 steel. Through jet impingement and double quenching process the toughness is almost 50% increase than conventional means. For maximum heat transfer at the stagnation point optimum H/d ratio was found to be 6 and is experimentally validated. Jet impingement quenching show a slight increase in hardness when compared to conventional quenching process. It is due to the reason that there is no vapor blanket stage in jet impingement quenching as al result heat transfer rate increases. Ultimately more martensite formation. In the double-quenching heat-treatment process, the toughness is increased because of grain refinement as the grain boundaries increase, it inhibits crack propagation and toughness increases. The structure become finer and results in the improvement of mechanical properties. Thus, the impact value is almost doubled that of single quenching.

Acknowledgment

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