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EFFECT OF THERMAL BARRIERS ON THE MARTENSITIC TRANSFORMATION IN A BAR JOMINY

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Abstract: The shape and geometry of a part influence the cooling behavior during a martensitic transformation; an experimental study carried out on a control Jominy bar was compared with other bars fitted with one, two, and three slots; the results show differences in hardness along the specimen, the hardness with a slit and more is greater than the hardness on a sample without a slit, this is valid on the cooled side of the specimen, the further away from the side cooled plus the difference is minimal; the study was completed with a simulation on bars with and without slits, the results of the temperature contours show an acceleration of the cooling on the cooled side of the bars provided with slits; far from the cooled face the influence of the slits is weak.

KEYWORDS: Jominy quenching, thermal Obstacle, numerical simulation, heat transfer.

1 Introduction

The Jominy quenching test is used to characterize the hardenability of steels by measuring hardness along the bar, the curves obtained tell us about the quenching and the ability to form martensite. The sample is first heated up to austerization in an oven, then quenched at the base by a jet of water coming out of a nozzle, the structure and hardness are affected by the cooling rate which decreases away from the bottom. High hardness values are found at the bottom and gradually decrease along the length of the sample.

The shape and dimensions of the part to be treated influence on the temperature development as well as the cooling medium, Šmak et al. [1] selected three types of cooling medium to analyze changes in mechanical properties and structural transformations. Cervantes-García et al. [2] experimentally studied a cylindrical bar under isothermal and non-isothermal conditions, to characterize the cooling curves, the results indicate that the dynamics of the fluids vary according to the cases and historical temperatures were collected.

Boonluang [3] studied the influence of the radius and therefore the geometry of the sample on the hardness during quenching, a relationship was built to predict hardness as a function of the radius. Liu et al. [4] studied the variation in mechanical properties and the microstructure of a flat part after quenching. Kim [5] simulated the carbide quenching process to interpret the three-dimensional effects of heat treatment of gear, the theoretical results were compared with experimental data. Simha et al. [6] developed a hardness model to obtain by simulation of the quenching characteristics of a Jominy bar, the results obtained agree with those obtained experimentally.

Maisuradze et al. [7] presented an experimental and numerical estimation approach for the hardness and microstructure of a piece of Jominy bar, then verified on a driveshaft, the results obtained are in good agreement with the experimental values. Qamar [8] presented a tool to

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assess hardenability by simulating with a CFD method while using estimates of the heat transfer rate, the cooling rate was found to be sensitive to the water jet speed. Smoljan et al. [9] developed a mathematical model for the simulation of mechanical properties during quenching, mechanical properties were predicted taking into account their dependence on temperature, the model was able to simulate 3D parts, such as complex cylinders, cones, and spheres.

Trush et al [10] experimentally studied the effect of heat treatment on fatigue properties, they installed zirconium alloy samples in a medium containing oxygen, and they then noted an improvement in fatigue life. of fatigue life, and noticed the formation of a structure with a higher energy intensity of destruction. Moltasov et al [11] developed an analytical method for determining the stress state of thin sheets butt welded with asymmetric reinforcement, this method takes into account the eccentric application load on the tensile stress concentration. The results were compared with the finite element method, indicating good agreement.The aim of this study is to show the influence of thermal barriers on the behavior of a Jominy bar, by carrying out an experimental setup, the hardness along the Jominy bar was plotted and a comparison was made between the cases studied with samples of small notches; the evolution of cooling with a CFD code was simulated with a bar provided with obstacles at different levels.

2 Reading summary of curve Jominy

This test characterizes the hardenability of the selected steel, there is a decrease in the hardness of the cooled surface over the distance, as the bar undergoes progressive martensitic hardening, depending on the cooling rate; the martensitic transformation is revealed indirectly by measuring the hardness along a generatrix of the bar compared to the cooling point.

The result is a hardness curve, called the Jominy curve, useful for interpreting the hardenability quality of the steel; the cooling of a generatrix of the bar is therefore carried out at a decreasing rate from the face cooled by the water to the opposite side face. The cooling rate depends on the heat exchange surfaces, linked to the shape and volume of the part, it also depends on the nature of the quenching fluid, its initial temperature, and the speed of the jet.

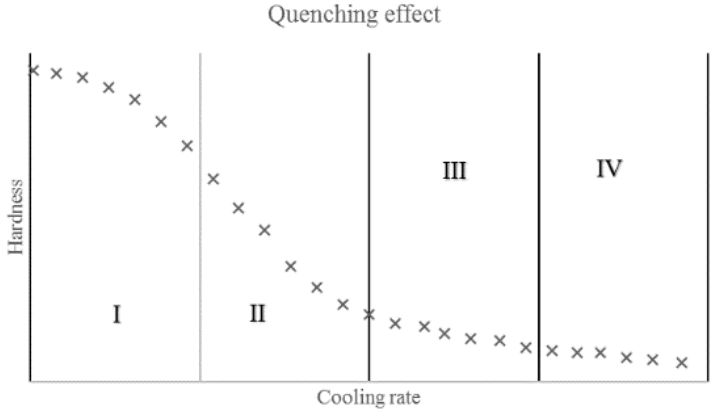


Fig. 1 Cooling rate and hardness zones associated

According to the literature [12-13], during martensitic quenching a tensile stress field is created, therefore deformed parts or scrap result. The quenching inhomogeneity of the metallurgical phase causes harmful local deformations of the parts; a limitation of the zones of the Jominy curve indicated in Figure 1, shows hardness margins by zone according to the rate of cooling; Figure 2 clearly shows the relationship between the cooling time, the distance between the cooled face, and the hardness at a given point.

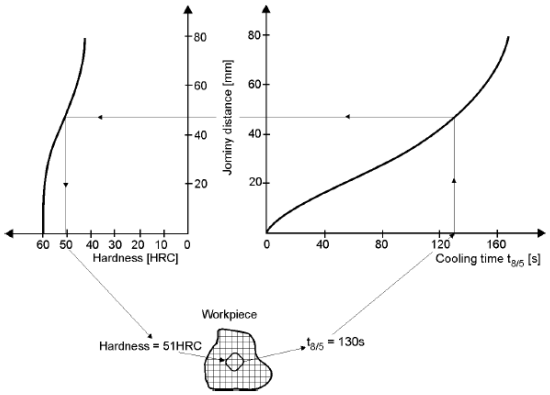


Fig. 2 Correlation between cooling rate and local hardness [14]

Table 1 gives the classification by domain, corresponding to quenching in a part in general, and in the Jominy specimen first. Besides the hardness obtained after treatment under different conditions, the Jominy curve contains interesting information. The martensitic starting stage, Zone I correspond to cooling conditions which only generate a martensitic transformation. Zone II defines the cooling conditions corresponding to the critical cooling martensitic transformation law. Beyond that, the structures are mixed. The variation in hardness beyond (Zone III and IV), informs us about the evolution of the structural state of the steel and therefore about the different proportions of residual martensite.

Table 1 Cooling and quenching effects

Designation		quenching effect and risk
I	excessive cooling	bearing martensitic very hard, cracks, distortions
II	moderate cooling	High and uniform hardness, no cracks, reduced distortion
III	Insufficient cooling	insufficient hardness and non-uniform, severe distortion
IV	slow cooling	Hardness reduced distortion limited

3 Experiment

3.1 Procedure and test equipment

The experimental analysis will focus on "Jominy bars" equipped with various notches and everyone will suffer the same heat treatment preceded by an annealing treatment relaxation. To complete the tempering treatment (TT) stress-relieving (SR), we replaced the furnace installation test Jominy with a precise CNC furnace. This experimental study involves a process modeled on the Jominy test to reveal the effect of the thermal barrier on the martensite phase transformation; for this, we opted for the measurement of the micro-hardness method for Vickers.

The local micro-hardness value corresponds to the hardness of the phase point. This will clearly explain the dispersion measurements observed on our Jominy curves. Four bars are available for the intended use, the notches simulating a disruption of the continuity of the material. The test specimens are of length L=100mm, section 20mmx23mm, and have been treated according to the rules of the art in order to ensure the integrity of the reception characteristics of the steel and to guarantee identical geometric dimensions of the test specimens. The notches made by milling have a depth and a width of 10mm (milling) of 11mm on the respective section of the specimen (20mm). The nomenclature of the samples is given as follows: Consider a sample without reference notches and a sample with a central notch, indicated in Figure 3; The other two specimens have 2 and 3 notches respectively.

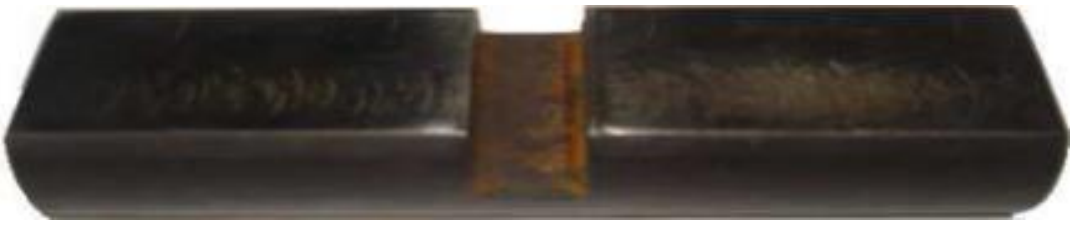


Fig. 3 Measuring with a central notch

The specimens were cut from a bar of square section steel quenching XC40, which was chemically analyzed by a laboratory of a steel factory in Annaba, see Table 2.

Table 2 Chemical composition of steel XC40

C	0.4	Sn	0.017	Mn	0.82
S	0.019	Cr	0.99	Si	0.19
V	0.01	Al	0.014	Ni	0.13
Cu	0.2	P	0.015	Mo	0.14
Fe 97.055					

Among the mechanical properties of the steel quenching, the XC40, well known in the standards, retains its strength Vickers indenter in the range of 170-195 HV to limit the out of 580-670 GPa. All specimens were annealed prior to a relaxation temperature of 550°C maintained for 60 min, followed by cooling in the furnace. In the same oven with a CNC furnace for thermal treatments, each specimen was heated continuously for 30 minutes to reach the temperature of 930°C. To ensure a complete austenitizing of the steel specimen is maintained for a further 30 minutes at this temperature. Jominy quenching is carried with natural water at 20°C, the specimen is placed on a grid and sprayed in conditions of Jominy.

3.2 Tests and results

The original intention of the annealing of relaxation (RD) is to eliminate, or at least reduce the constraints imposed at the time of certain process transformations such as machining or handling. The annealing of relaxation is always carried out at a temperature of heating lower than the minimal temperature of transformation (Ac1) for steels and cast iron. One cools then, at a sufficiently slow rate to avoid the formation of new constraints; The treatment of annealing of relaxation was proceeded in the following thermal cycle: Heating (automatic) progressive during 45 minutes, to reach the temperature of maintenance during 60 minutes; then a very slow cooling in the furnace.

In the context of this experimental analysis, the annealing of relaxation must allow an adjustment of hardness, useful for the characterization of the steel XC40, whose hardness is in the beach of HV 170-195.

The average hardness with the reception (or rough state) is HV 323 (fluctuation in micro-hardness), which was adjusted to an average level of HV 259 after RD for the test tube of reference, as shown below in figure 4. Consequently, this average hardness is beyond the average hardness characteristic of the XC40 which is about HV 183. We assume that these median values of hardness are representative of the unit of the test tubes placed at the disposal within the framework of this experimental analysis. It is retained since, in spite of the annealing of relaxation (500°C during 60mn), the real parts still have a residual hardness; the latter should disappear at the temperature from austenitization.

Two series of measures were carried out, the recto face comprising the notch and the back part of the test tubes; this series of measurements after annealing of relaxation is by no means fortuitous since it enabled us to characterize the tempered steel in question as well as possible,

namely the XC40. If we consider statistically that the average of all the hardness measurements, taken on all the test pieces, is the value characterizing our steel, we obtain the following summary table 3; the mean value for all the samples used is HV 261.

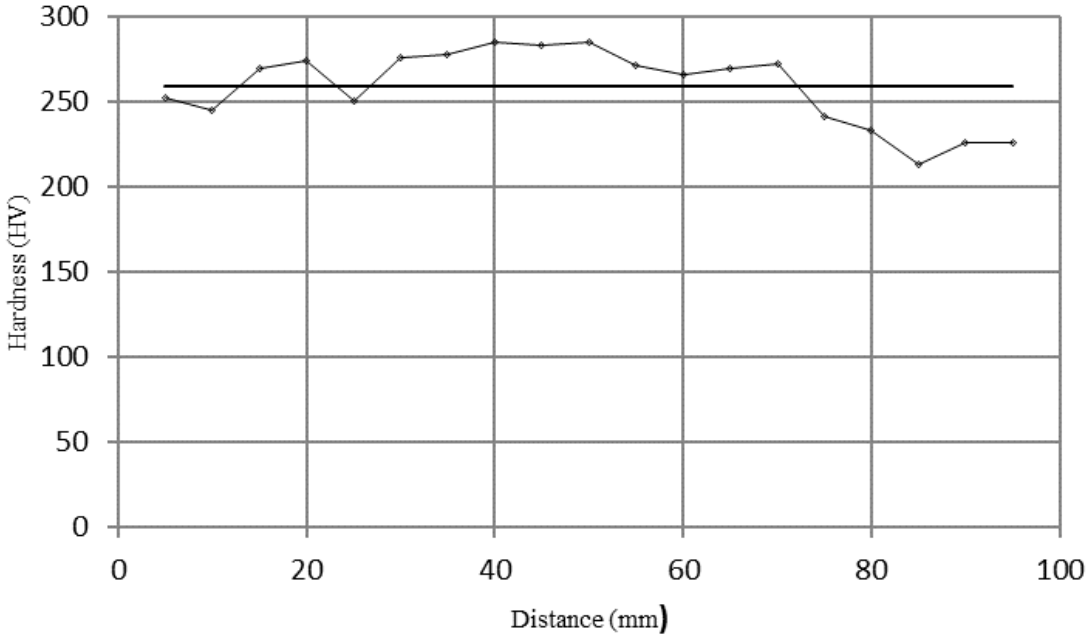


Fig. 4 Profile of hardness after annealing of relaxation

Table 3 Summary of average hardness after annealing

	Test tube			
	0 notch	1 notch	2 notches	3 notches
Recto	259	259	261	272
Verso	268	251	255	264
Mean HV	264	255	258	268
Global hardness mean HV 261				

After hardening and according to the same procedure as for the annealing of relaxation, on a parallel generator hardness is measured in the spacing of 5 mm. The resulting profiles of hardness sound are represented in figure 5 and show the difference in hardness before and after hardening. Before hardening hardness has a median value with a narrow margin of variation according to the distance; after hardening hardness decreases according to whether one moves away from the point of cooling. That is to say, distance zero of the test tube; then one moves away and more hardness falls according to a curve of tendency, one notices a margin of error compared to the curve of the tendency of to the type of measurement of hardness, which is a specific micro-hardness.

Figure 6 shows the hardness of the test tubes with notches, we represented only hardness before the first notch and after the third notch for the three test-tube, to be able to compare them. One notes a downward trend of hardness then, for the three test tubes, as soon as one moves away from the cooled face, the hardness of the test tube with 2 and 3 notches are higher than that of a notch and are all higher than 0 notches. This is valid before the obstacles, after the obstacles there are no differences; dispersions noted compared to the tendency are due partly to the type of measurement by micro-hardness.

Figure 7 represents the hardness of the test tubes that have notches on the face back without notches, hardness decreases when one moves away from the surface cooled, the bearish

tendency is for the three types of test tubes, the fluctuations of hardness observed are due to the type of measurement which we used.

4 Numerical simulation

It should be noted that the speed of cooling is complex because it is conditioned by the transfer of heat in the fluid of hardening (its speed of sprinkling or dissipation of the heat). by the transfer of heat to the interface metal-fluid of hardening (effect shielding thermal) and finally by the transfer of heat in metal (with its physical and geometrical inhomogeneousness) [15-16]. A simulation with a CFD code was made by reproducing the dimensions of the Jominy bar, with the initial and boundary conditions defined below.

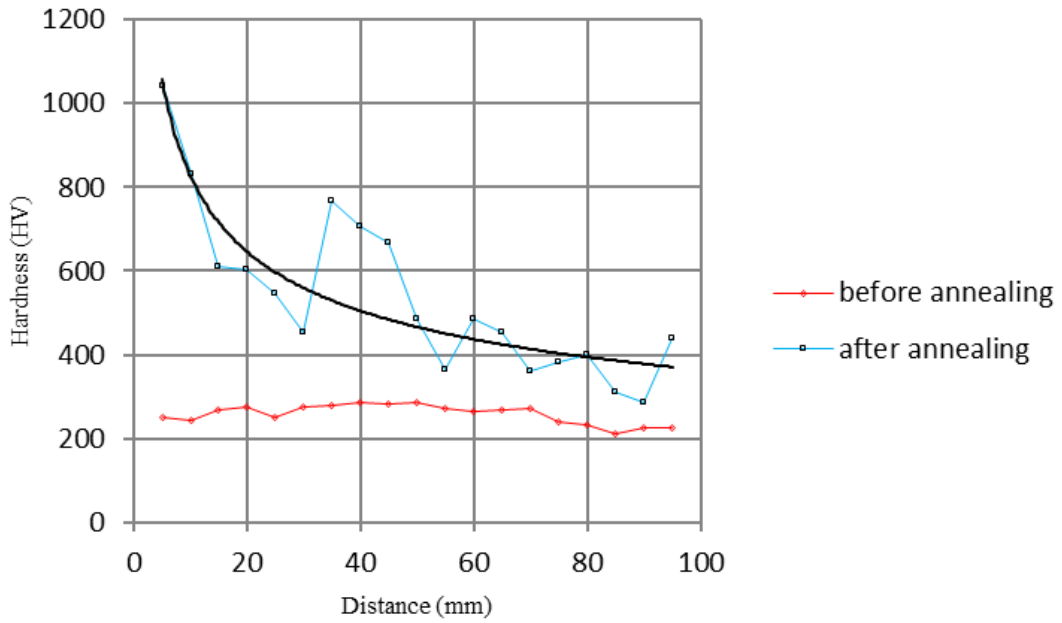


Fig. 5 Profile of hardness before and after hardening of the test-tube reference

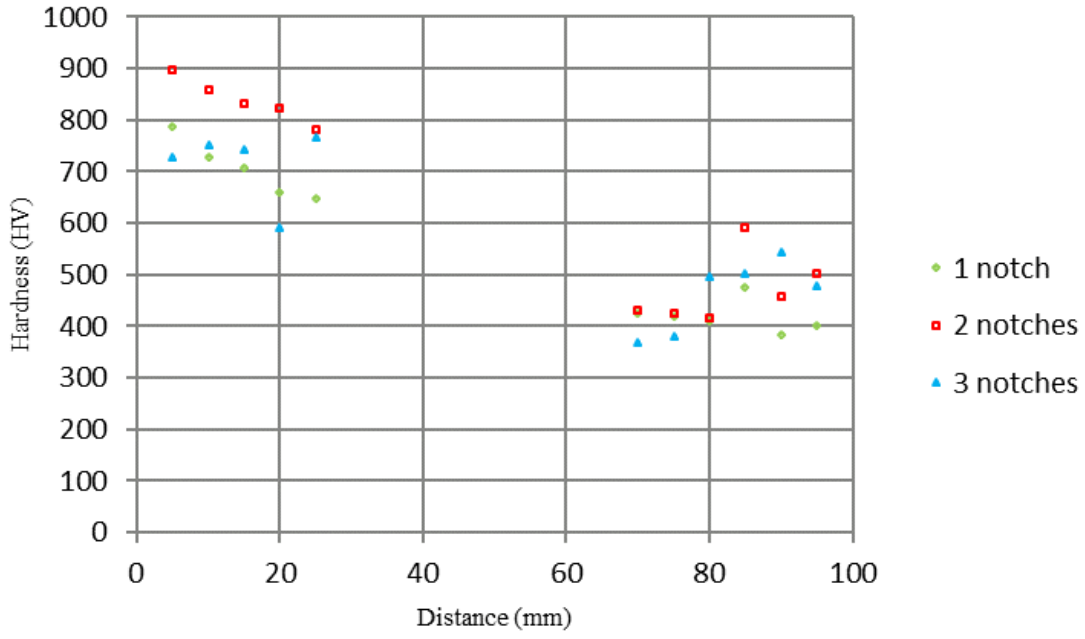


Fig. 6 Profile of hardness after hardening of the test-tube on the face of notches

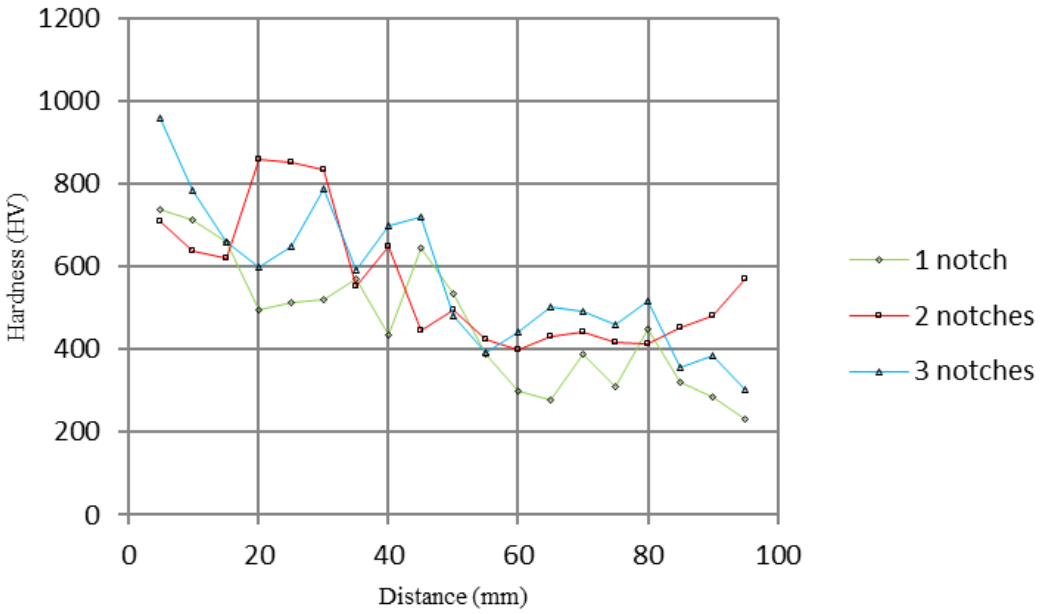


Fig. 7 Profile of hardness after hardening of the test tubes on the face without notches

4.1 Domain of simulation

The domain of selected control is dimensions 100 mm x 20 mm according to the dimension of the test-tube in 2 dimensions. We chose a uniform mesh of 0.5x0.5 the low part is the surface to be cooled with an ascending water jet (wall), the other faces are cooled with the ambient air, and are of two verticals types or horizontal. Calculations will be made in Cartesian coordinates; all the types of test-tubes will be simulated; with know-knowing without a notch, and those with one, two, and three notches, as indicated in figure 8.

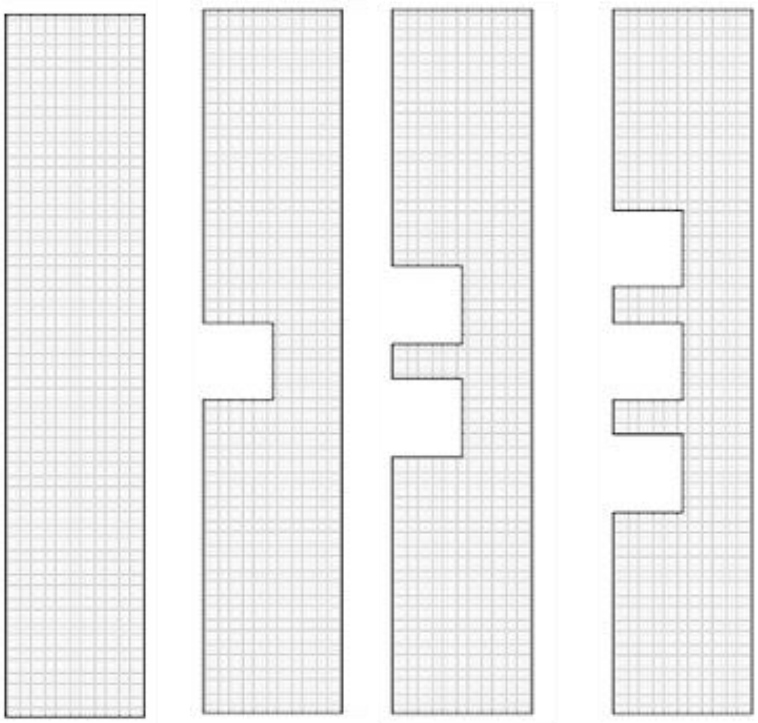


Fig. 8 Domain of simulation

4.2 Boundary and initial conditions

The lower face is cooled by a water jet, for the four specimens, the coefficient of transfer of heat is calculated starting from the equation (1) for a coefficient of Prandtl equal to 1, according to Bejan and Kraus [9]. The others faces are cooled by natural convection of the air; we have two cases who present ourselves, that is to say, the faces are horizontal and the coefficient of transfer of heat is calculated with the equation (2); or the faces vertical and one uses the equation (3), the formulas are drawn from the book Heat Transfer Handbook de Bejan and Kraus [17]. Nu, Re, Pr, and Ra are respectively the Nusselt, Reynolds, Prandtl, and Rayleigh Numbers.

$$Nu = 0.332 Re^{\frac{1}{2}} Pr^{\frac{1}{3}} \tag{1}$$

$$Nu = 0.54 Ra^{\frac{1}{4}} \tag{2}$$

$$Nu = \left\{ 0.825 + \frac{0.387 Ra^{\frac{1}{6}}}{\left[1 + \left(\frac{0.492}{Pr} \right)^{\frac{9}{16}} \right]^{\frac{8}{27}}} \right\}^{2} \tag{3}$$

The temperature of the unit is carried to 930°C, the temperature limits lower after cooling is that of AC1, after this limit of 721 °C, it does not have there more transformation. The characteristics of steel will be taken with the average temperature of 825 °C, the characteristics of steel were drawn delivers Heat Transfer Handbook de Bejan and Kraus [17].

The temperatures used for the calculation of the formulas (1), and (2) will be the average temperature of the environment which is 25 °C and that of steel taken equalizes with 825 °C, that is to say, a temperature of 425 °C or 700K, a number Ra=1.75 106 and one Pr=0.684 were found for this case. The characteristics of water for the formula (3) were taken equalized with 100°C; We then found a heat transfer coefficient for air equal to approximately 10 W/m ² K; a heat transfer coefficient for water equal around 5000 W/m ² K for a number of Re =2 104 and one Pr= 11.1; which will be applied for lower surface, other surfaces will have a coefficient calculated for air.

4.3 Results of simulation

After the introduction of the initial conditions and the specifications of the boundary conditions, the control of the solution, as well as initialization, must be specified before starting of calculation, the diagrams of discretization of the various variables and the factors of under relieving were retained by default, the step of time used is of 1seconde.

By introducing the initial conditions with the grid, while launching the calculus, we obtain contours of the temperature of the test-tube with 0 notch, the recorded temperatures are that on the face from the length to distances from 5, 15, 25, 75, 85, and 95 mm. We chose three points, before the position of the notches and three others after the notches.

The starting temperature is 1203.15 K on all the face length, after 3 minutes the position to 5 mm at the lowest temperature follow-up of that of 15 and 25 mm.

On the other hand, with 75, 85, and 95 mm the difference in temperatures between these positions tiny, like is indicated in figure 9; Mehmet Cakir and Abdullah Ozsoy [18] found these same results.

After 3 minutes (180 seconds) one obtains the contour of the temperatures for the four specimens, it is noted that contours are right and parallel with the face of water cooling.

For the others contours are curved, the more the number of notches increases and more the face of water injection is quickly cooled since the contour of 400 K moves away from the face; one also notices that the contours of temperatures are practically the same one after notches, see figure 10.

By comparing the cooling of all the test-tubes with the position of 5 mm of the face, one notes that the more the number of notches increases and the more cooling is accelerated, this phenomenon attenuates with time since all the temperatures meet as the Figure 11 indicates it.

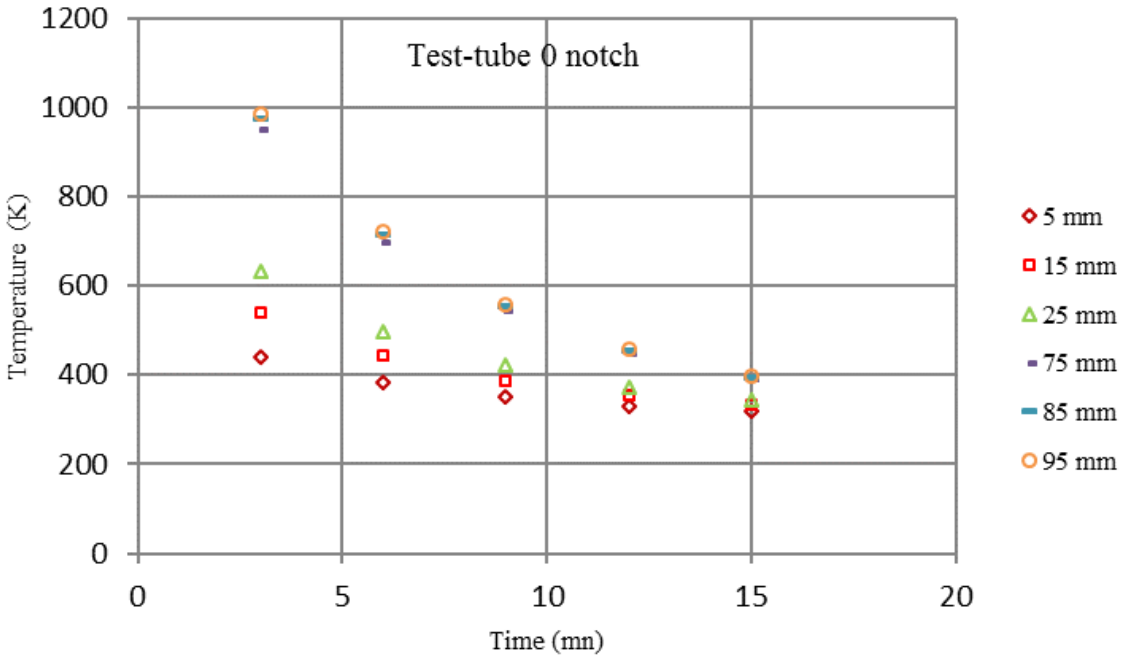


Fig. 9 Change of the temperature according to time on the face of the test-tube with 0 notches

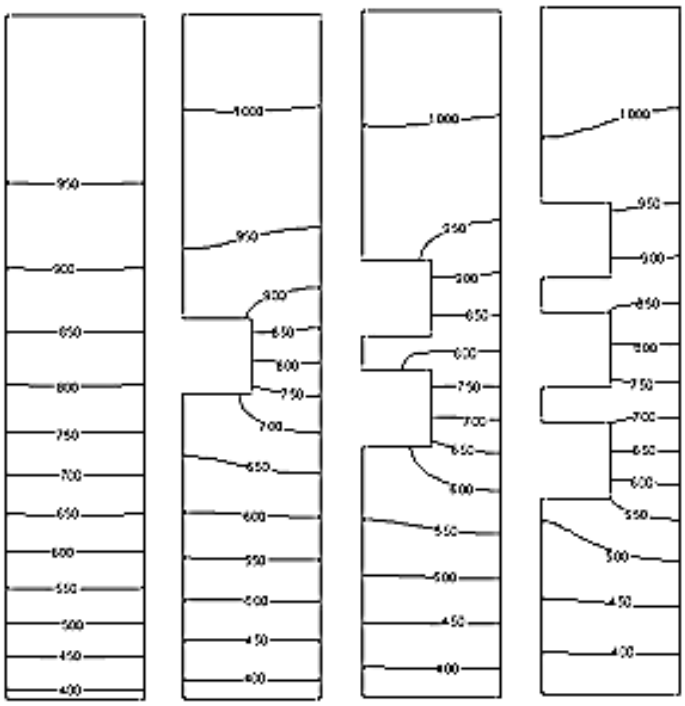


Fig. 10 Contour of the temperature after 180 seconds

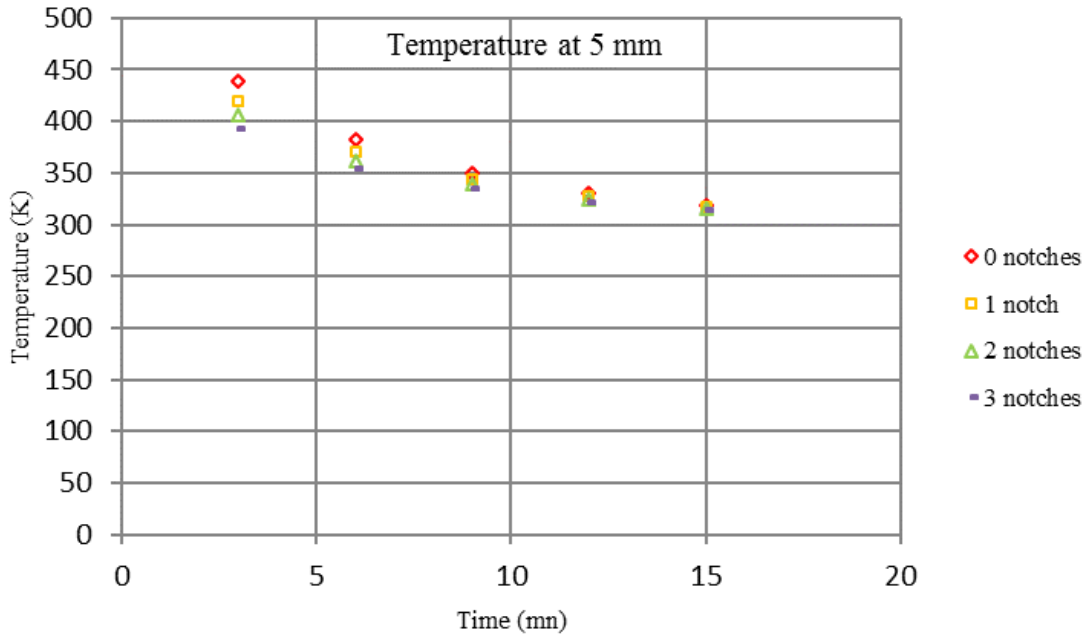


Fig. 11 Change of the temperature according to time at 5mm

CONCLUSION

An experimental study was carried out on Jominy test specimens, with 1, 2, and 3 notches; after quenching the hardness measurement indicates a downward trend as one moves away from the cooled face, the hardness at 2 and 3 notches is greater than one notch and are all greater than 0 notches, this is valid on the cooling side, beyond the notches the influence is minimal.

The simulation made with a CFD code showed that when the number of notches increases the cooling is accelerated, this is valid for the positions close to the water jet, Beyond the

notches far from the cooling face, the influence of the notches of test specimens is minimal on cooling.

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