EFFECT OF VARIOUS SPRAY COOLING CONFIGURATIONS ON HARDNESS PROFILE OF TUBES

STRANSKY MAREK[1], BROZOVA Tereza[1], RAUDENSKY Miroslav[1], HNIZDIL Milan[1], TURON Rostislav[2]

[1]*Brno University of Technology, Faculty of Mechanical Engineering, Heat Transfer and Fluid Flow Laboratory, Brno, Czech Republic, EU*
[2]*Trinecke Zelezarny a.s., Trinec, Czech Republic, EU*

Abstract

Heat treatment is one of methods to improve material properties. Heat treated tubes are used in petrochemical industry when high strength, low cost and low weight are needed. Spray cooling could be used for heat treatment because very high cooling intensity is required. This paper deals with influence of spray cooling parameters on the material hardness.

Special device was developed by Heat transfer and fluid flow laboratory for quenching of small samples. Four different materials were tested. The main object of these tests was to find the influence of cooling distance, material and two-side cooling on material hardness. Device Innovatest Nexus 4303 (Vickers) was used to measure hardness in various depths from the cooled surface. Results showed that the hardness was improved for all of four materials. The influence of the spray cooling distance was not so significant. Hardness of material also depends on the cooling intensity in the inner side of the tube. If the cooling intensity in the inner side of the tube is much lower than external, it has negligible effect on the final hardness. If the inner and external cooling intensity is the same it causes increase of the hardness.

Keywords: Hardness, Vickers, quenching, heat treatment, spray cooling, tube

1. INTRODUCTION

Heat treatment is a technological process which improves mechanical properties of material such as hardness, strength and so on. It is characterized by moving of hot material through the cooling section. The most important part of heat treatment is controllability of cooling rate [1]. Other important parameters are chemical composition and thermal conductivity of the material. They have strong influence on the hardening capacity.

The design procedure of cooling sections for heat treatment is a process where optimal cooling rate has to be found. A continuous cooling transformation diagram (CCT) is usually computed to characterize the material behavior [2]. CCT diagram and numerical simulations are used to find the optimal cooling rate to achieve required mechanical properties and material structure [3]. CCT diagrams are not so accurate because they are measured using very small samples [4]. The next step is verification of the cooling intensity and its dependence on the material structure in real time. The first part of this verification is steady-state hardening capacity test (similar to Jomini test). The second part is a full scale experiment using real sample moving through the cooling section in the real time.

This paper describes the experimental research of the steady-state hardening capacity tests (Jomini tests) for various materials typically used for tubes production. The main object of these tests was to find the influence of the cooling distance, material and two-side cooling on material hardness.

2. MEASUREMENT DEVICES AND EXPERIMENTAL PROCEDURE

2.1. Hardening capacity test

The hardness capacity test bench was developed by the Heat transfer and fluid flow laboratory (**Fig. 1**). It is composed of the furnace, tested sample, nozzles and pneumatically driven deflector. The experiment started by heating the sample to the austenization temperature. Austenization time was around twenty minutes. Nitrogen was blown into the furnace during heating and austenization to prevent oxidation on the sample surface. Then the water pump was switched on and required water pressure was set. The furnace was moved up by the lift and the sample was moved under the spray. The deflector was in the position between the water jet and the sample. The deflector was quickly pushed away so the water started to spray on the surface of the sample.

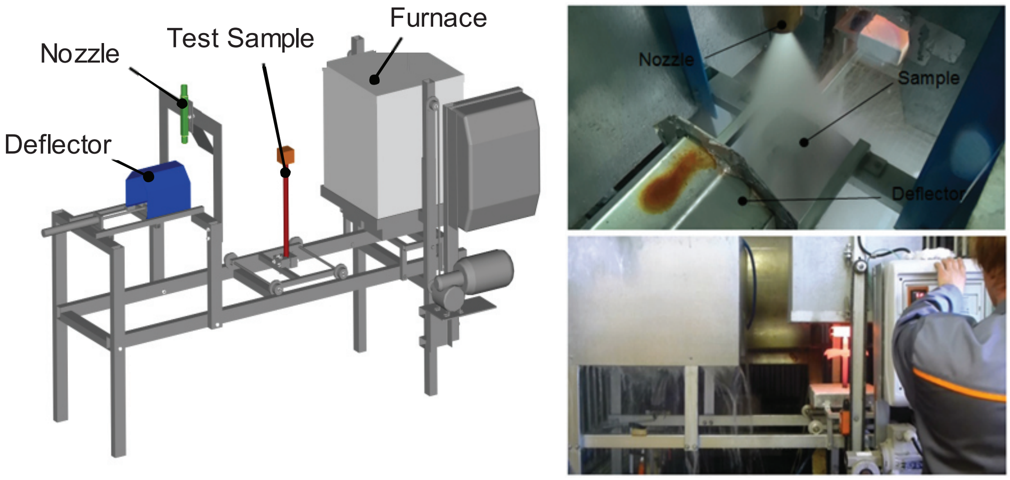

Fig. 1 Hardening capacity test bench

2.2. Innovatest Nexus 4303, Vickers hardness measurement device

Quenched samples were used for hardness measurement. They were sawed in the centerline of the sample body in the water spray direction by an electro-erosive machine. Measured surface of the sample was grinded and polished. Hardness measurement device was used to measure the material hardness. It was Innovatest Nexus 4303. This device was bought by the Heat transfer and fluid flow laboratory for measuring hardness. The main load was ten or thirty kilograms for ten seconds. It depends on material hardness. The distance between measured points was two millimeters (close to the sprayed surface) and five millimeters (far from the sprayed surface). Pictures of the measurement device and sample are in **Fig. 2**.

Fig. 1 Hardness measurement device Innovatest Nexus 4303 with tested sample on the table

3. EXPERIMENTAL SAMPLES AND RESULTS

Four various samples were prepared for tests using tubes produced by Trinecke zelezarny a.s. The materials of these samples were 20MnV6, 42CrMo4, 4140 and x65. Dimensions of these samples were different, because of the various tube thicknesses. Other tested parameters were spray distance and cooling difference between one and two side cooling. Other experiment conditions are specified in **Table 1**.

Table 1 Description of tested parameters

Experiment Sample	Material	Sample Dimensions	Type of cooling	HTC of upper nozzle/ bottom nozzle	Distance between sample and nozzle
		[mm]		[Wm^{-2}K^{-1}]	[mm]
1	20MnV6	50x50x60	one side cooling	35 000	170
2	42CrMo4	50x50x50	one side cooling	35 000	170
3	4140	50x50x50	one side cooling	35 000	170
4	x65	50x50x20	one side cooling	35 000	200
5	x65	50x50x20	two side cooling	35 000 / 35 000	200
6	20MnV6	50x50x60	two side cooling	35 000 / 35 000	170
7	20MnV6	50x50x60	one side cooling	35 000	115
8	20MnV6	50x50x60	two side cooling	35 000 / 15 000	170
9	20MnV6	50x50x60	one side cooling	35 000	181
10	x65	50x50x25	two side cooling	35 000 / 15 000	200

3.1. The influence of the material on the hardness

The influence of the material on the hardness profile was measured (samples 1 - 4). A Lechler nozzle with heat transfer coefficient (HTC) around 35 000 Wm^{-2}K^{-1} was used. The samples were sawed after experiment and hardness was measured in various depths from the cooled surface. Hardness of original material was also measured and these two results were compared. Pictures of samples are shown in **Fig. 3**.

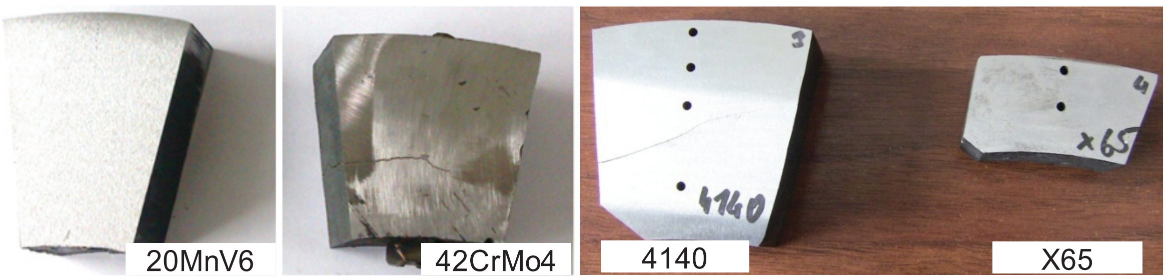

Fig. 3 Example of samples of different materials

Results of measurements are shown in **Fig. 4** and **Fig. 5**. The hardness was improved by quenching for tested samples. The materials 4140 and 42CrMo4 showed the same behaving. The hardness of original materials was slightly higher than 300 HV. The hardness of tempered materials (cooled from only one side) increased to almost constant value of 700 HV. Both of samples cracked inside (**Fig. 3**). Hardness of second couple of materials (20MnV6 and x65) was also improved especially to depth of 10 mm from sprayed surface. The hardness decreased from value around 500 HV (1 mm under surface) to value around 300 HV. This value was then constant to the non-cooled side of the tested sample.

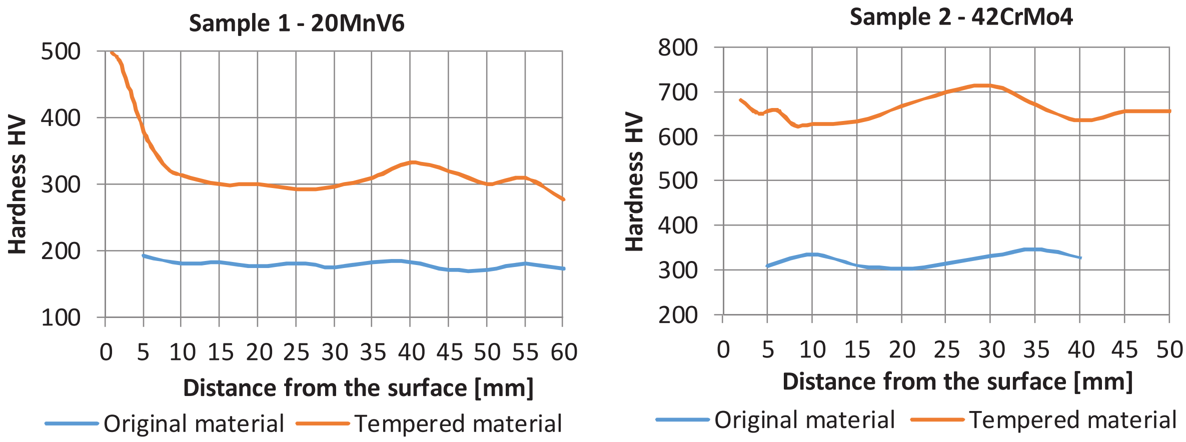

Fig. 4 Results of hardness measurements for samples 20MnV6, 42CrMo4 - original and quenched material

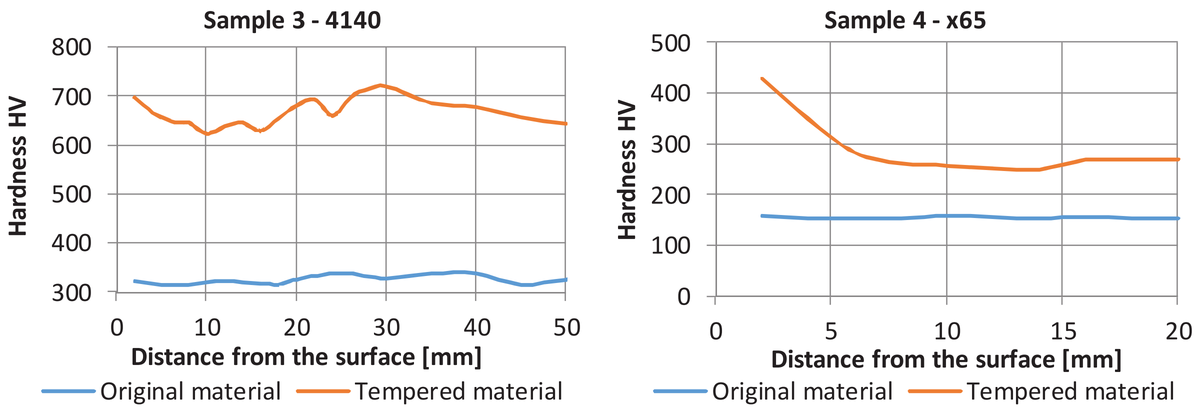

Fig. 5 Results of hardness measurements for samples 4140, x65 - original material and quenched material

3.2. The influence of the spray distance on material hardness

Next tested parameter was the spray distance. The same Lechler nozzle with HTC around 35 000 $Wm^{-2}K^{-1}$ was used for cooling from various distance. Sample 20MnV6 was used for these tests because of the previous results and its bigger thickness. Measured distances were 181 mm, 170 mm and 115 mm (samples number one, nine and seven). Results of these experiments were very interesting again. The influence of spray distance was almost negligible even if the different heat transfer coefficient was predicted for each test [5] [6]. The thermal conductivity of samples was very low so the surface was cooled down very fast. Results of these experiments are shown in **Fig. 6**.

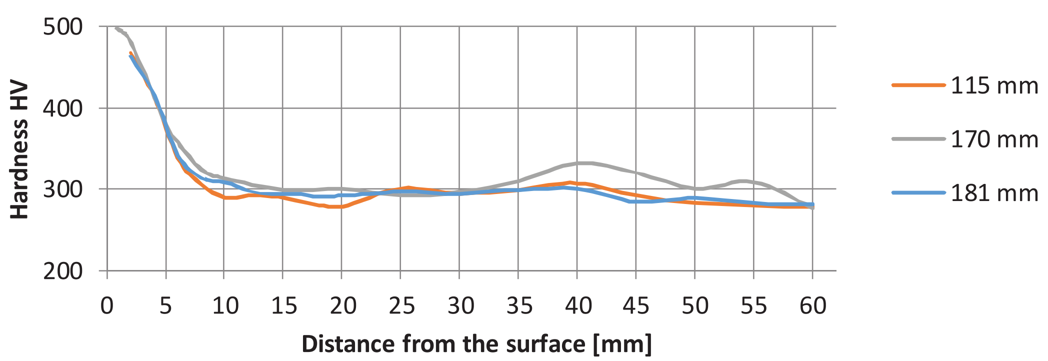

Fig. 6 Hardness measured for samples cooled from various distances - Sample 20MnV6

3.3. The difference between one and two side cooling for various nozzles

The last part of this research was aimed on the influence of internal and external cooling on the material hardness. Two materials were chosen for these tests (20MnV6 and x65). Three cases of different cooling were studied and compared. First case was only upper cooling using Lechler nozzle with HTC around 35 000 $Wm^{-2}K^{-1}$. Second case was symmetrical cooling using the same nozzle from internal and external part (upper and internal cooling). The last part of these tests was done with non-symmetrical cooling. Nozzle with HTC around 35 000 $Wm^{-2}K^{-1}$ was used for upper cooling and nozzle of HTC around 15 000 $Wm^{-2}K^{-1}$ was used to simulate internal cooling. Results were similar for both tested materials. The hardness was improved for symmetrical cooling from both cooled sides. Non-symmetrical cooling result showed that the hardness of the material was significantly improved only from upper part (500 - 300 HV) to the depth of 10 mm.

A material had also influence on sample hardness. Hardness of material 20MnV6 was almost the same for only upper, symmetrical and non-symmetrical cooling in the center of the sample (depth between 10 mm to 50 mm from the surface). But hardness of material x65 was improved for symmetrical both side cooling in the center of material (from 10 mm to 15 mm from the upper surface). It was caused by the relatively smaller thickness of the sample.

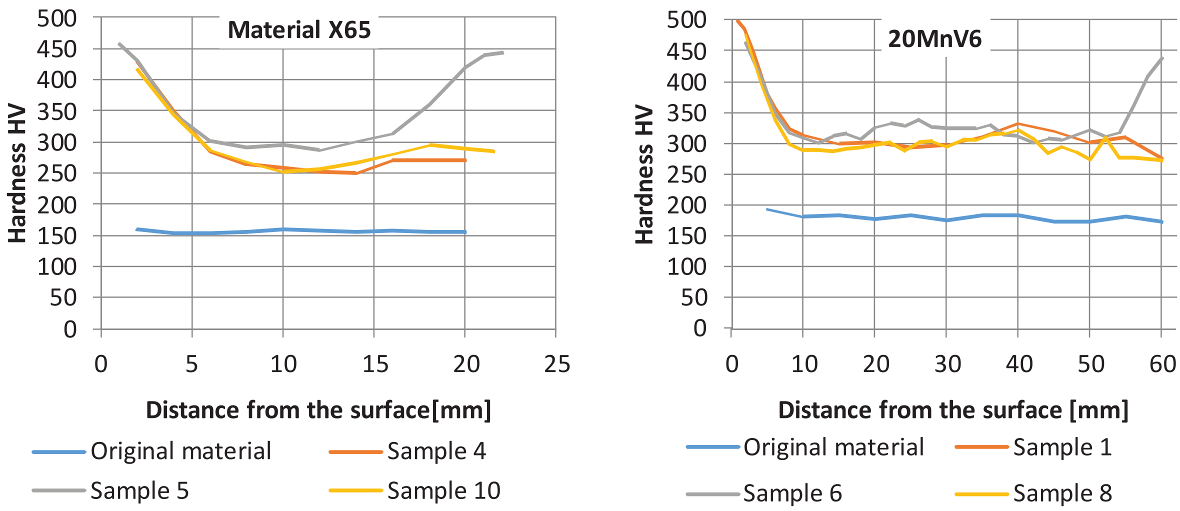

Fig. 7 Results of hardness measurements for samples x65 and 20MnV6 and various cooling conditions. Blue curve represents hardness of original material. Red curve is for only upper cooling. Other two curves are for two side cooling (internal and external cooling) - green from symmetrical cooling (the same HTC) and purple for non-symmetrical cooling (lower HTC for internal cooling)

4. CONCLUSION

Four different kinds of materials (20MnV6, 42CrMo4, 4140 and x65) usually used for tube production were tested by hardening capacity test. The influence of material, nozzle distance and two-side cooling on material hardness was tested. A Lechler nozzles of HTC around 35 000 $Wm^{-2}K^{-1}$ and 15 000 $Wm^{-2}K^{-1}$ were used. Hardening capacity test bench was developed by the Heat transfer and fluid flow laboratory. These tests are like Jominy test except the dimensions and shape of the sample. Innovatest Nexus 4303, Vickers hardness measurement device was used to measure hardness in the body of the experimental sample. The hardness capacity test bench and Vickers measurement device are shortly described in chapter 2.

The influence of the material was significant. Hardness of materials 42CrMo4 and 4140 was improved significantly in the whole body. Original hardness of these two materials was little bit higher than 300 HV. Measured hardness after hardening was around 700 HV. So it was improved more than 2 times. The behaving of materials 20MnV6 and x65 was similar. Their original hardness of 200 HV was improved to a value around 500 HV in area very close to the sprayed surface. Then this value was decreasing with depth increase to a value of 300 HV in depth 10 mm from the sprayed surface and remained constant in the rest of the sample body.

Next part of these experiments was to find the influence of spray cooling distance on the material hardness. Only two materials were chosen for these tests with respect to previous results. They were 20MnV6 and x65. The same Lechler nozzle with heat transfer coefficient (HTC) around 35 000 $Wm^{-2}K^{-1}$ was used for these experiments. Three different spray distances were tested (115 mm, 170 mm and 181 mm). Different HTC values were predicted, because the distance between nozzle and hot surface has significant influence on the cooling intensity. Results showed that these different spray distances have negligible influence on material hardness. The heat transfer coefficient was too high to cool down very fast from different distances and conductivity of the material was low. That's why the change of distance had negligible influence on the final hardness in the body.

Last part of this paper describes the influence of one and two side cooling with symmetrical and non-symmetrical HTC distribution. First test was done using cooling from the top side of the sample. Second test was done with both side cooling (upper and internal part of the sample) with the same nozzle of HTC around 35 000 $Wm^{-2}K^{-1}$. Two different nozzles were used for the third experiment. Upper nozzle was the one with HTC around 35 000 $Wm^{-2}K^{-1}$ but the bottom nozzle (internal cooling) had HTC around 15 000 $Wm^{-2}K^{-1}$. It was found that the symmetrical cooling improved hardness from both side equally. The hardness was decreasing with increasing depth - from 500 HV to a value 300 HV in ten millimeters from the sprayed surface. Very interesting results was found for non-symmetrical cooling from both sides. It was found that the lower internal cooling has negligible effect on material hardness of material 20MnV6 and very low effect on material x65. This difference showed that there is an influence of the material and its thickness.

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