THE RECESSION OF HARDNESS IN SAMPLES, CUT BY PLASMA, AFTER NORMALISING PROCESS FOR STEELS 65MN4 AND 40CR4

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Annotation: There are researched possibilities to reduce hardness in thermal influence area for spring steel 65Mn4 and alloy steel 40Cr4, cut by low temperature plasma. There are defined if the most efficient reduction of hardness comes about 850 °C. In this temperature the hardness of samples becomes equivalent to initial hardness of material in time about 4…5 minutes.

Key words: plasma, cutting, hardness, steel.

Introduction

More often for producing of plane details (thickness 5-20 mm) use low temperature (≈ 4000 °C) plasma cutting. This method provides to reduce labor intensity of producing, appropriate roughness and shape of details, has enough productivity and rational operation of materials. In process of cutting microstructure of manufactured detail, mechanical, deformation and technologic characteristics is changed. Particularly, these changes express itself in area of thermal processing; the width of this area depends on capacity of plasma torch, plasma's temperature, cutting's speed, microstructure and chemical composition of material. The hardness in area of thermal processing can rise substantially [1-4]. The change of microstructure is unwanted for details, which ones are for further handling by welding, or mechanical treatment as turning, milling, extending and making room for cutting bores and thread cutting in bores. In this cases producers have interest how much the hardness is increased in area of cutting, gradient of hardness recession, width of thermal processing area as well as the sort of technology for reducing of hardness and value of reduction, the labor intensity and profitableness of one or the other technology. In literature is possible to find the answers about methods for reduction of hardness in samples, cut by plasma: full annealing, isothermal annealing, partial annealing, high-temperature tempering, normalizing. For making a choice of the thermal treatment method for the hardness reduction, after cutting by plasma, one of the most important criterions is the reduction of energy consumption and product cost of processing.

Materials and methods

The least of hardness has achieved after full annealing, but this process is with high energy consumption as well as the furnace is occupied for a long time. The same problems are using isothermal annealing. The method of partial annealing usually uses for hypereutectoidal steel marks. In comparison with methods, mentioned above, this one is less energy consumption as well as the details are heated and annealed in lower temperature. The high-temperature tempering has performed using more low temperature (about 600 °C), but obligatory demand is to hold detail in this temperature at least for 30 min. The advantage of normalizing method is minimal time of detail holding in furnace after heating, practically at once it is taken out of the furnace and cooled by open air, thereby, furnace isn't occupied and energy isn't spent for detail heating. The normalizing method is more efficient, when for the heating of detail hard surface there are used the induction current or smelt lead bath. The disadvantage of induction current method is necessity to make new inductor for each detail, cut by plasma, with different size and configuration. If one inductor is used and detail is moved, the efficient isn't too serious, especially for big perimeter details. The lead bath method is related with problem of human protection from hazardous fumes.

The objective of the research is to clarify, how the hardness changes in preparations, cut by low temperature plasma, in thermal influence area for spring steel 65Mn4 and alloy steel 40Cr4 samples after normalizing, depending of heating temperature and duration of holding after this temperature.

The samples, cut by plasma were used. The experimental cuts were made by automatic equipment SATO ELECTRONIC CNC-801, which one performs by schema of direct operation with low temperature plasma arc. The diameter of plasma torch nozzle is 3 mm, diameter of wolfram electrode is 2.5 mm, and for making plasma air was used. Cut was made by speed 90 mm/min. After cutting details were cooled in room temperature. The size of samples is 15x40 mm.

Table 1

The chemical composition and width of examples

Material, steel	Width of example, mm	Chemical composition, %					
		C	S	P	Mn	Si	Cr
65Mn4	13	0.62-0.70	0.040	0.035	0.70-1.0	0.17-0.37	≤ 0.25
40Cr4	10	0.36-0.44	0.040	0.035	0.65	0.17-0.37	0.95

The hardness of examples out of thermal influence area was estimated by Brinell's method, concerned LVS EN ISO 6508-2 "The metallic materials. Brinell's hardness test", by using of 10mm hardened steel bead, load 3000kgf and by providing this load 10 s and using of Rockwell's method concerned LVS EN ISO 6508-1 "The metallic materials Rockwell's hardness test". The hardness of examples in thermal influence area and in cutting surface was estimated by Rockwell's method (HRC). Before estimation of hardness in thermal influence area, examples were rubbed up by rubber disc.

Results and discussions

The width of thermal influence area is estimated as length in which the hardness of detail surface catches-up with surface hardness before plasma cutting. The hardness changing gradient in thermal influence area close to cutting plane was estimated by method of micro-hardness estimation.

The hardness of estimated examples before cutting in cutting plane and maximal hardness growth ΔHRC and ΔHB is set in Table 2.

Table 2

The hardness of estimated examples before cutting in cutting plane and maximal hardness growth ΔHRC and ΔHB

Material, steel	Hardness, HB	Hardness in cutting plane			Growth of hardness	
		Upper part	medium	lower part	ΔHRC	ΔHB
65Mn4	210	42	51	38	39	324
40Cr4	212	36	46	38	35	255

After cutting by plasma, the hardness of samples from steel 65Mn4 in cutting plane was estimated as HRC 51±2. Hardness of samples from steel 40Cr4 in cutting plane was estimated as HRC 46±2.

The dependence of width of thermal influence area on hardness measurement place and cutting speed w is set in Table 3.

Table 3

The dependence of width of thermal influence area on hardness measurement place and cutting speed w

Material, steel	Width of thermal influence area, mm			
	w=60 mm/min		w=90 mm/min	
	Close to torch	lower part	Close to torch	lower part
65Mn4	1.2	1.7	0.9	1.5
40Cr4	1.6	2.0	1.1	1.9

For these materials maximal hardness and width of thermal influence area in the upper part (close to torch) is less then it is in the sample lower part.

With increasing of the cutting speed from 60 to 90 mm/min, maximal hardness in cutting area and width of thermal influence area decrease.

The results of research micro-hardness in thermal influence area for sample of steel 65Mn4 and 40Cr4 are showed in Fig. 1.

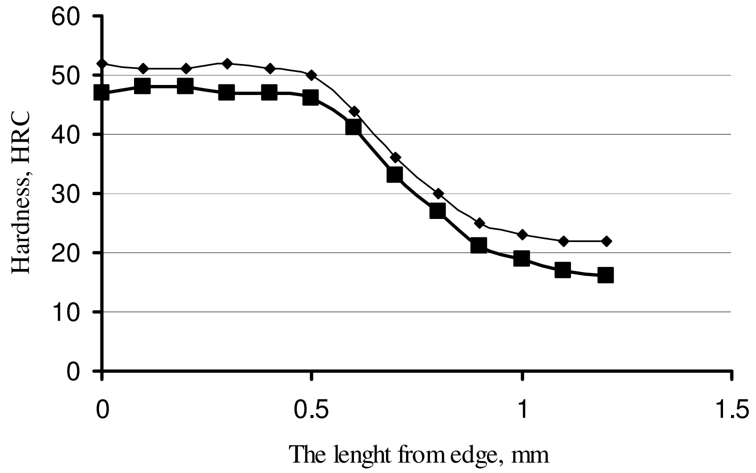

Fig. 1. **The recession of micro-hardness in thermal influence area for sample of steel 65Mn4 (♦) and steel 40Cr4 (■)**

The results demonstrates, if hardness of steel 65Mn4 in area approximately 0.5 mm from cutting edge is practically constant – approximately HRC 51 ± 2. As well as by moving away from the cutting edge, the hardness decreases and at the length 1.1 mm hardness become the same as initial hardness of the material.

After cutting by plasma, in the cutting place, forms thermal influence area with variable hardness.

The maximal growth of hardness for samples, which ones were researched is observed in the middle and lower part of cutting plane.

To clarify, how temperature affects the hardness of sample in thermal influence area, the sample is heated in muffle furnace for a 60 s. in constant temperature. Then samples are taken out and cooled on open air by temperature 20 °C. The temperature of furnace for steel 65Mn4 is 210, 420, 630, and 850 °C. The temperature of furnace for steel 40Cr4 is 650, 700, 750, 800 and 850 °C.

The dependence of samples hardness on heating temperature is set in Table 4.

Table 4

The dependence of samples hardness on heating temperature

Version	Material	Heating temperature, °C	Holding time, s	Hardness, HRC±2
1.	65Mn4	210	60	51
2.	65Mn4	420	60	51
3.	65Mn4	630	60	51
4.	65Mn4	850	60	38
5.	40Cr4	600	60	48
6.	40Cr4	650	60	48
7.	40Cr4	700	60	47
8.	40Cr4	750	60	45
9.	40Cr4	800	60	43
10.	40Cr4	850	60	40

The results demonstrate, if for steel 65Mn4, the reduction of hardness is more efficient in temperature 850 °C, for steel 40Cr4 the reduction of hardness is begin in temperature 750 °C.

To clarify, how hardness changes depending on holding time, the samples are inserted in muffle furnace by temperature 850 °C and taken out after certain time, then samples are put on steel plate. The time is estimated, in which samples cool, by open air, till room temperature and then the hardness in cutting plane is estimated.

The dependence of samples hardness on holding time for sample of steel 65Mn4 and 40Cr4 (w = 90 mm/min) in furnace by temperature 850 °C is set in Fig. 2.

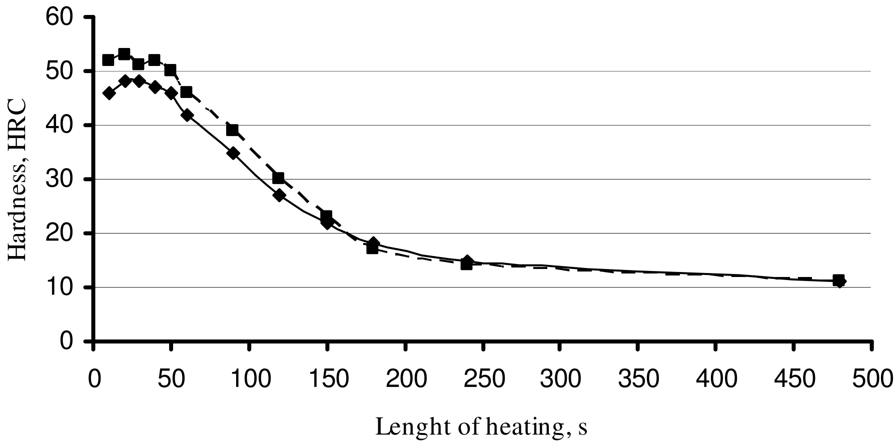

Fig. 2. **The dependence of samples hardness on holding time, steel 65Mn4(■) and steel 40Cr4 (♦)**

The results demonstrate, when heating time increases for steel 65Mn4 and 40Cr4, the hardness in thermal influence area reduces nonlinearly.

Serious reduction of hardness by temperature 850 °C comes on after at least 40 s. Example - for sample of steel 65Mn4 (w = 90 mm/min) lower part with high credibility (R^2 = 0.9897) the changes of hardness expresses coherency:

$$HRC = - 5E\text{-}08\ t^4 + 3E\text{-}05\ t^3 - 0.005\ t^2 + 0.0734\ t + 51.009. \quad (1)$$

Conclusions

1. The results of experiment demonstrate, if the efficient method for hardness reducing in thermal influence area for details, cut by plasma, is heating of these by temperature 850 °C, holding, in dependency on desirable hardness value and cooling by open air in room temperature.
2. The hardness of samples, used in the research, after holding in furnace and cooling by open air, become equivalent to initial hardness of material in time about 4…5 minutes. Samples grew cold till the room temperature in 3-5 min. time.

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