THE RECESSION OF HARDNESS IN PREPARATIONS AFTER CUTTING BY PLASMA

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Abstract. Are compared different cutting processing of tabulate steel preparations and it is discovered that in area of thermal processing of preparations, after cutting by plasma, the hardness, microstructure and quality of surface change; the changes depend on carbonic content in unalloyed steel.

There is evaluated the effect of alloyaged elements to width of thermal influence area and recession of hardness depending on the speed of cutting and current intensity.

Key words: plasma, cutting, hardness, steel.

Introduction

The most efficient method for the production of irregular tabulate steel preparation is cutting from sheets. It is enforced by different methods: gas cutting, voltaic arc cutting and laser cutting, cutting by water fluidic, and cutting by punching as well as by plasma cutting.

Each of the mentioned methods has advantages and disadvantages, which are connected with chemical composition, physical mechanical properties, and the thickness of preparations, the volume of output, the after-treatment technology of preparations of working material as well as profitability and other factors.

The gas cutting is appropriate for different thickness steels, but not efficient for nonferrous metals as well as alloys of these metals. For voltaic arc cutting there is not required any specific equipment, but cutting place is very rough. After laser cutting there is evenly cut surface, but there are problems to cut unalloyed steel sheets as well as steels with high carbonic content, other problem is high production costs because of high-priced equipment.

The method of cutting by water fluidic is appropriate for non thick materials as well as it are not possible for cutting in the middle part of detail. Cutting by punching is fast and precise, but it is appropriate only for not very thick blanks. Cutting by plasma is one of the most universal methods; it is efficient for different steel marks and alloys of nonferrous metals with thickness under 300 mm.

More often for producing plane details from different marks of materials there is use low temperature (~4000 ^oC) plasma arc cutting. This method provides a possibility to reduce labor intensity of producing, appropriate roughness and shape of details, has enough productivity and rational operation of materials. In the process of cutting microstructure of the manufactured detail, mechanical, deformation and technologic characteristics are changed. Particularly, these changes express themselves in area of thermal processing; the width of this area depends on the capacity of plasma torch, plasma's temperature, cutting speed, microstructure and chemical composition of material.

The hardness in area of thermal processing can rise significantly. The change of microstructure is unwanted for details, which are meant 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 has 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 profitability of one or the other technology. In literature [1, 2, 3] it is not possible to find the answers to all these questions about all materials, producers are interested in. Application of these information is inconvenient enough as well as producers do not use yet EN material marking system fully.

The other reason is if different metal producers practically do not produce materials with completely identical chemical composition and mechanical properties and eventually the quantity of different marks of materials, used in mechanical engineering is wide, but information about it is not enough available.

For evaluation, how the most important factor – plasma radiant (plasma torch) affects different materials, in work [1] is offered to simulate cutting process with supposition, if temperature θ on the blank surface behind plasma torch affection area is described by coherency:

$$\theta = \frac{k}{\lambda v} \cdot \sqrt{\frac{\omega}{\pi \tau}}, \tag{1}$$

where k – the intensity of plasma radiant, J/m;
λ – coeficient of thermal conductivity for treated material, W/m·K;
ω – coefficient of temperature conductivity for treated material, m^2/s,
v – speed of torch movement, m/s;
τ – period of time, since torch moving away from the point, where temperature is measured, s.

When the researching how the width of thermal influence area *t*, mm is depends on current intensity, it is found that thermal influence area, when 16 mm thick alloyed steel 35XH2CM (RU marc) is cut, increases from 4.8 to 6.5 mm (if current intensity increases from 200 A to 290 A) and decreases from 4.8 to 2.2 mm if speed of cutting increases from 6 to 13 mm/s. Further increasing of cutting speed does not significantly decrease area of influence.

The width and shape of clearance depend on cutting regime, especially on speed. The preferable speed of cutting *w*, (m/h) can be calculated [2], from arc current intensity *I*, A; arc voltage U; coefficient of arc efficiency η; the intensity of heat returning of metal ζ, W; the density of metal ρ, kg/m^3; width of cutting *b*, mm; thickness of metal δ, mm; growth of metal enthalpy ΔS, J/kg, by coherency:

$$w = \frac{0.24 \cdot I \cdot U \cdot \eta - \zeta}{\rho \cdot b \cdot \delta \cdot \Delta S}. \tag{2}$$

The criteria for cutting quality are: size of tolerance, the perpendicularity of cutting surfaces, roughness of cutting surface and width of thermal influence area. Thereby, arc consists of three parts with different efficient heat capacities – cutting surface of middle thick and thick details forms in the shape of cones.

Materials and methods

To clarify, how width of thermal influence area changes depending on carbonic content in unalloyed steel as well as effect of alloyed elements to width of thermal influence area and nature of recession of hardness as well as to update direction for further researches, have performed experimental researches of hardness and microstructure with steel marks: S235J2, C20, C45, 65Mn4 unalloyed construction steels, C80U unalloyed instrumental steel, 40Cr4 un 30CrMnSi 4-4-3 alloyed construction steels samples. The samples' thickness was chosen from 8 to 13 mm.

The experimental cuts were made by automatic equipment SATO ELECTRONIC CNC-801, which 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. The speed of cutting for unalloyed and low-alloyed steels was varied: one cut was made by speed 120 mm/min, other – by speed 170 mm/min. In steels 40Cr4 and 65Mn4 cuts were made by speeds 60 and 90 mm/min. After cutting details were cooled in room temperature. The shape and cutting trajectory for researching examples is shown on Figure 1.

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

Fig. 1. **The shape and cutting trajectory of steel sample C80U**

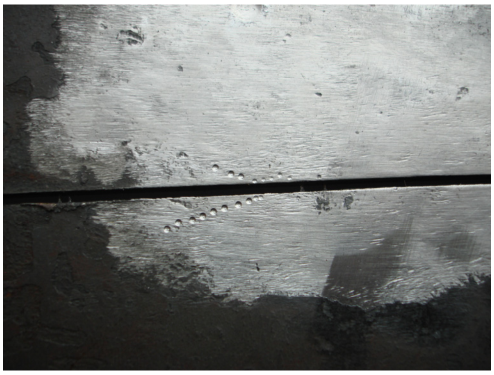

Fig. 2. **Sample of hardness measuring HRC in cutting area**

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 detail microstructure was estimated in magnification X200.

The samples for hardness estimation in cutting area were cut by abrasive disc. The chemical composition and width of samples are given in Table 1.

Table 1. **The chemical composition and width of samples**

Material	**Width of sample**	**Chemical composition, %, max**					
Steel	mm	C	S	P	Mn	Si	Cr
S235J2	8	0.17-0.22	0.045	0.045	1.50	-	≤ 0.25
C20	10	0.17-0.24	0.040	0.035	0.35-0.65	0.17-0.37	≤ 0.25
C45	10	0.42-0.50	0.040	0.035	0.5-0.8	0.17-0.37	≤ 0.25
C80U	10	0.75-0.85	0.030	0.030	0.1-0.4	0.10-0.30	≤ 0.25
65Mn4	13	0.62-0.70	0.04	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
30CrMnSi 4-4-4	10	0.28-0.34	0.040	0.035	0.95	1.05	0.95

The hardness of estimated samples before cutting, in cutting plane and maximal hardness growth ΔHRC and ΔHB are given in Table 2.

Results

The results shows, that for unalloyed steels C20, C45, C80U, hardness in cutting plane as well as content of carbonic increases. The maximum of hardness rate is in the medium part of examples, but the lowest – in the upper part (torch side).

The changes of upper part hardness in thermal influence area for steels C80U, C45, C20, 30CrMniSi4-4-3 and cutting speed (*w*) 170 mm/min are given in Table 3.

Table 2. **The hardness of estimated examples before cutting in cutting plane and maximal hardness growth Δ HRC and Δ HB**

Material	Hardness	Hardness in cutting plane			Growth of hardness	
Steel	HB	upper part	medium	lower part	ΔHRC	ΔHB
S235J2	163	21	16	18	19	58
C20	146	17	20	16	28	71
C45	187	27	31	28	27	104
C80U	269	35	53	47	29	327
65Mn4	210	42	49	38	39	324
40Cr4	212	42	53	53	40	385
30CrMnSi 4-4-4	235	30	30	39	26	145

Table 3. **The changes of upper part hardness in thermal influence area for steels C80U, C45, C20, 30CrMniSi 4-4-3 and cutting speed (*w*) 170 mm/min**

The length from edge	Hardness, HRC ±2	Micro-structure	Hardness, HRC ±2	Micro-structure	Hardness, HRB±3 (HRC)	Micro-structure	Hardness, HRC ±2
	C80U		C45		C20		30CrMnSi 4-4-3
0	35	Pearlite	31	Pearlite	95 (17)	(P+F)	35
0.7	28	Pearlite	24	Pearlite+ ferrite (P+F)	86 (7)	(P+F)	40
1.0	25	Pearlite	18	(P+F)	85 (6)	(P+F)	24
1.2	21	Pearlite	13	(P+F)	84 (5)	(P+F)	20
1.5	19	Pearlite	11	(P+F)	83 (4)	(P+F)	17
1.7	18	Pearlite	10	(P+F)	81 (2)	(P+F)	16
2.2	18	Pearlite	10	(P+F)	78 (0)	(P+F)	15

The changes of hardness in thermal influence area for 10 mm width instrumental steel C80U sample upper and lower part are given in Figure 3.

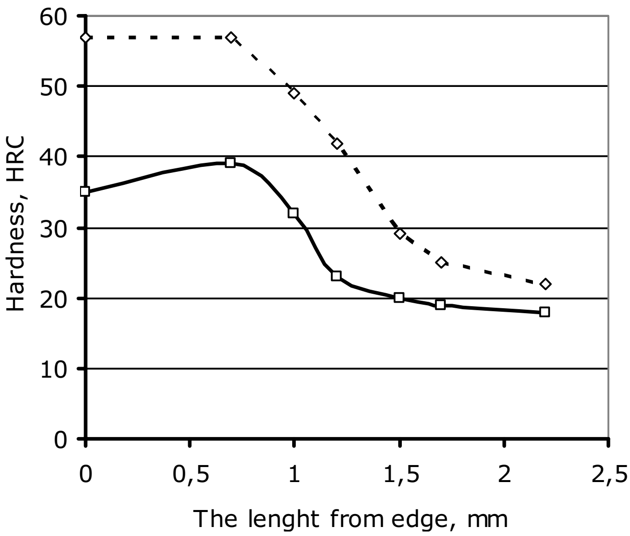

Fig. 3. **The changes of hardness in thermal influence area for steel C80U sample, the speed of cutting *w* = 120 mm/min**: - - - lower part; — upper part of sample.

The results demonstrate that hardness of sample surface in thermal influence area grows less in places close to torch than it happens in the opposite side (lower part). The same conclusion is true for all researched marks of steels.

Hardness HRC in thermal influence area depending on length from cutting plane (*t*), changes nonlinear and this connection is expressed by polynomial in the fifth power.

Example – for sample of steel C80U (*w* = 120 mm/min) lower part with high credibility (R^2 = 0.9969) the changes of hardness express coherency:

$$HRC = -3.7232\,t^5 + 22.476\,t^4 - 31.95\,t^3 - 14.615\,t^2 - 10.70\,t + 57.$$

The dependence of width of thermal influence area on hardness measurement place and cutting speed *w* are given in Table 4.

Table 4. **The dependence of width of thermal influence area on hardness measurement place and cutting speed *w***

Material	Width of thermal influence area, mm			
Steel	*w* =120 mm/min		*w* =170 mm/min	
	Close to torch	lower part	Close to torch	lower part
S235J2	0.6	1.0	0.5	0.9
C20	0.5	1.4	0.5	1.0
C45	1.4	2.0	1.1	2.0
C80U	1.5	2.2	1.2	2.3
30CrMnSi 4-4-4	0.8	1.0	1.5	1.8
	w = 60 mm/min		*w* = 90 mm/min	
40Cr4	1.6	2.0	1.1	1.9
65Mn4	1.2	1.7	0.9	1.5

As we can see, the thermal influence area in place close to torch is tighter, than at the lower part, as well as width of thermal influence area grow in connection with increasing of carbonic content. Width of thermal influence area for alloyed steels is wider than it is for unalloyed steels with low and medium carbonic content.

The recessions of hardness in thermal influence area for 10 mm width alloyed construction steel 30CrMniSi 4-4-3 are observed in thermal influence area with the width of 1.8 ± 0.2 mm. The thermal influence area measurements demonstrate that hardness in the part, which is cut in the cutting plane, is: in place close to torch or in the upper part in deep approximately 0.8 mm and in the middle on average – HRC 30 ± 3; in the lower part – HRC 39 ± 2. The microstructures are structures of hardening pearlites.

The results of research micro-hardness in thermal influence area for sample of steel 40Cr4 are shown in Figure 4.

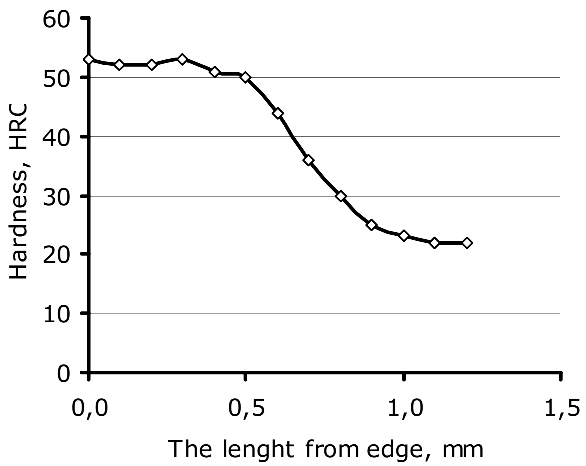

Fig. 4. **The recession of micro-hardness in thermal influence area for sample of steel 40Cr4**

The results demonstrates that hardness of steel 40Cr4, in the area which is approximately 0.5 mm from cutting plane, 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 becomes the same as initial hardness of the material.

Conclusions

1. For all materials, which were researched, after cutting by plasma in the cutting place, creates thermal influence area with variable hardness.
2. As well as carbonic content increases, maximal hardness of unalloyed steels in cutting area and width of thermal influence area, increase too.
3. For all materials, which were researched, maximal hardness and width of thermal influence area in the upper part (close to torch), is less than it is in the sample's lower part.
4. The supreme growth of maximal hardness in cutting area from materials, which were researched, have steels 40Cr4 and 65Mn4.
5. With increasing of the cutting speed from 120 to 170 mm/min, maximal hardness in cutting area and width of thermal influence area decrease.
6. The maximal growth of hardness for samples, which were researched, is observed in the middle and lower part of cutting plane.

Literature

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