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Influence of the speed in advance and the laser's power on the zone affected thermically for steel C45

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Abstract: *The Laser cutting is a very important manufacturing technology. But this method has some disadvantages, among which we find the emergence of a Thermically Affected Zone ZAT can dramatically alter the characteristics of the processed material which affects its behaviour during its use. For this, we have tried in this article to study the effect of the forward speed and the laser power in this area (thickness, hardening). In this context, tests were made on steel C45 where we relied on the method of experiment plans to create a mathematical model Significant coefficients are obtained by carrying out a variance analysis ANOVA on the level of 5% of significance. We find that the speed in advance and the power of the laser have a great effect on the ZAT.*
Keywords: *Cutting, Laser CO2, Heat Affected Zone.*

I. Introduction

The ZAT is obtained when the temperature of the sample of steel becomes higher or equal to the specific temperature of the first structure of transformed metal. Steel is transformed into austenite. During the cooling, austenite undergoes a phase shift of the solid state and is transformed into martensite. The sample preserves the same chemical composition that austenite, but it changes of crystalline structure quadratic. Martensite has a great tenacity for simple steels. The part of the steel which undergoes this austenitic transformation is called the ZAT (Thermically Affected Zone). The ZAT can be characterized by mechanical micro hardness testing and optically by an optical microscope. These measurements are used to estimate the width of the ZAT in the morphology of the optimal cut. Neila Jebbari al. [1] have studied the ZAT metal C45 with the assistance of CO2 gas. Fig. 1 shows some examples of grooves with different machining conditions. ZAT, characterized by whitish areas surrounding the grooves are clearly observable in the photos. The morphology of the ZAT is quite repetitive in general. It is possible to note a reduction in width when going towards the bottom of the groove. In Fig. 1 (a), irregularities on the edges of the groove can be observed. This can be attributed to the effect of feedback, which is created when the beam diameter is small impact. The effect of the laser power can be observed in Fig. 1 (c) (P = 2500 W), wherein the depth of the groove is twice as large as those of FIG. 1 (a) and (b) (P = 1500 W). When the cutting speed is high, the groove depth and width of the ZAT become weak due to the short time of laser-matter interaction (Fig. 1 (d)). Fig. 1 (b) is obtained in optimal machining parameters, where a great regularity in the form of the groove and of the TAZ can be noticed. ZZAT widths of ZAT were measured at the top of the groove and the average values are displayed on the experimental curves.

Fig.2 shows the evolution of the experimental value of the width of the ZAT (Z_{ZAT}) depending on the diameter D of laser impact. (Z_{ZAT}) increases to a maximum at D = 0.17 mm, and thereafter, it decreases to a limit value. This result confirms the possibility of using the interaction time (increasing with D) and the laser power density (decreasing with D) to optimize machining.

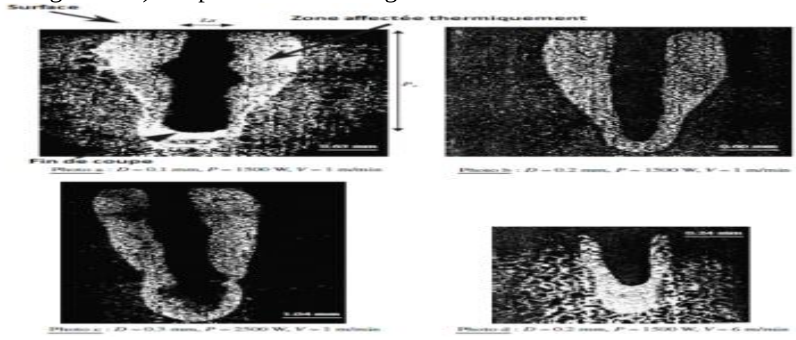

Fig.1 Morphology of the ZAT

Fig. 3 (Z_{ZAT}) shows that changes linearly with $\sqrt[4]{P}$ and at the same time, it is linear with V^{-1} (Fig. 4). In general, the width of the ZAT as a linear function of $\sqrt[4]{P}$x V^{-1}, it can be written as follows:

$$Z_{ZAT} = \gamma.\frac{\sqrt[4]{P}}{V} + \delta$$

Fig. 5 shows that γ and δ depends on the diameter D and the impact of the beam. At the optimum value of the diameter D of the laser impact (D = 0.17 mm) and from the fitted curves of Z_{ZAT} (Fig. 5), it can be deduced that γ = 0.0012mm$^{0.75}$ (kg s)$^{-0,25}$ and δ = 0,027 mm.

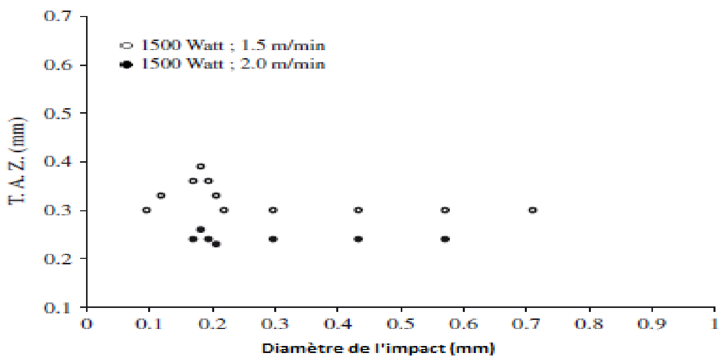

Fig.2 Influence of the diameter of the laser beam at the impact on the width of the ZAT

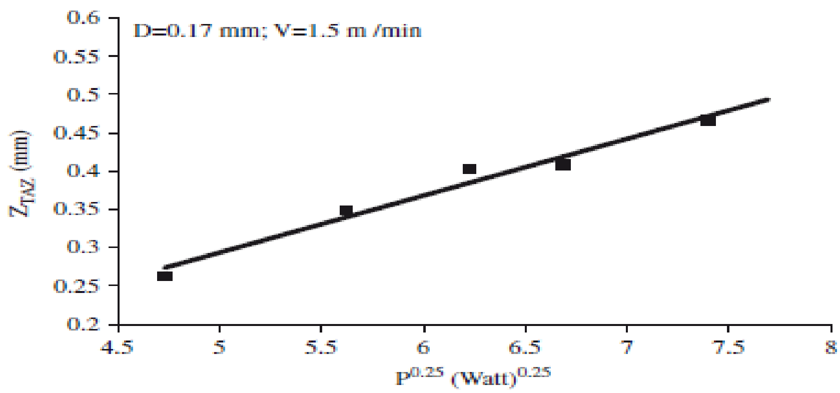

Fig.3 Influence of the power of the laser across the width of the ZAT

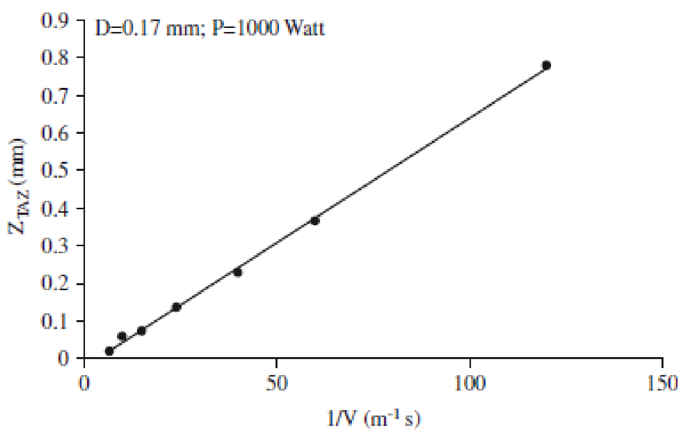

Fig.4 Influence of cutting speed on the width of the ZAT

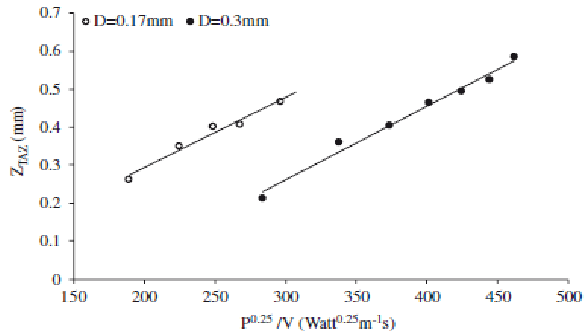

Fig.5 Influence of γ and δ over the width of the ZAT

In the same context, there is more research on the HAZ made by IA Choudhury and S. Shirley [2], these experimental trials have studied three different types of thermoplastics polypropylene (PP), polycarbonate (PC) and polymathy methacrylate (PMMA).

Davim et al. [3] reported in their research that the HAZ PC was between 0.1 and 0.3mm and that of PMMA was between 0.05 and 0.25mm. Thus the results of this research [2] is reasonably agree with those of Davim et al. [3]

The size of the ZAT reflects the quality of laser cutting of polymeric materials. The ZAT data were used to develop the model equations for the input parameters (cutting speed, laser power and air pressure). These equations are as follows:

$$ZAT_{PP} = 18.1\ P^{0.47}\ V^{-0.189}\ p^{-0.035}$$

$$ZAT_{PC} = 16.996\ P^{0.485}\ V^{-0.233}\ p^{-0.199}$$

$$ZAT_{PMMA} = 5.657\ P^{0.572}\ V^{-0.158}\ p^{-0.058}$$

These equations represent an overview of the extent of the HAZ and its dependence on the parameters of laser treatment. The analysis of variance for all these equations has proved sufficient, at intervals of 95%. Ratios lack of adjustment to the pure error in all cases was less than the F-statistic of 9.01. From these equations, it is clear that the ZAT is extended with the laser power and decreases with the cutting speed and air pressure. The laser power is the most important variable affecting the ZAT. More cutting speed, the lower the duration of combustion and therefore smaller ZAT. Other tests that highlight the influence of the feed rate made by J. Wang and WCK. Wong [4] concluded that if the feed rate and low ZAT will be of considerable thickness, so to get a good surface quality with minimal ZAT, it was necessary to increase the feed rate. This study is in agreement with the total research done with L. Shanjin and W. Yang [5], which has the same tests but changing the type of gas assistant using argon and compressed air. (Fig.11). After CO_2 laser cutting, a thermally affected zone ZAT occurred is covered by a thin white layer [6], this area is under the influence directly by the laser power and Pu feed speed Vf.

Experience:

The experiments were made in the company LASER Industires in Tunis; the machine used is TRUMATIC L3030 that has a capacity of 5000W maximum switching. Was used as the material of steel C45 The chemical composition and mechanical properties are given in the tables (Tab 1 and Tab 2). The reason for choosing this type of material is its frequent use in general industry which gives great importance to the possibility of improving its cutting qualities. The choice of cutting conditions was based on experience and some preliminary tests. Assistant gas pressure is 16 bar, the laser frequency is 20 000 Hz with a distance de1.2 mm from the nozzle. We chose three different speeds (560 mm / min, 1400 mm / min and 2240 mm / min) with 4 different power levels (3 kW, 3.5 kW, 4 kW and 5 kW), where 12 samples.

Tab 1: Chemical Composition of the C45

	Fe %	S %	Mn %	C %	Si %	P %	Mo %
C 45	98	0.045	0.5 → 0.8	0.45 → 0.5	0.4	0.045	0.1

Tab 2: Physical properties of the C45

	R (Mpa)	Re (Mpa)	A%
C 45	730	410	17

Each sample was passed through a series of preparation before starting the analysis. Firstly, they were coated, and then did the polishing, then made chemical attack; it was used for the 3% Nital which consists of 3% Nitric Acid and 97% Ethanol. Each sample was visualized by optical microscope to operate the modification of the

ZAT metal and to measure it. They were then passed through the SEM (scanning electron microscope) in order to visualize the white layer. Then, it was microhardness tests to know the evolution of the hardness in the ZAT. After that, we measured the surface roughness with two different devices (3S Surface Scan for 2D profiles and MICROMESURE 2 for 3D profiles).

II. Result and discussion :

2-1 Width of ZAT

The principle of laser cutting is greatly heated surface of the material to be cut until it melts and the molten part will be removed with the assist gas. But on the other hand, it is absolutely necessary to find a game that is warm to a temperature that could change its metallurgical and mechanical characteristics; this part is called the heat affected zone (ZAT).

Found below (Table 3) the results obtained under extreme conditions when measuring the width of the ZAT after an observation with an optical microscope (Fig. 6).

Tab.3: Width of the ZAT as a function of cutting parameters

Num	Vf (mm/min)	Pu (W)	ZAT (μm)
1	560	3000	164,526
2	2240	3000	126,062
3	560	5000	231,638
4	2240	5000	143,017

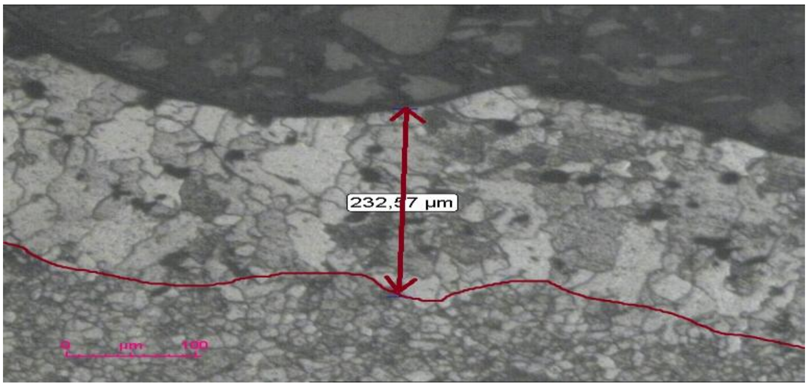

Fig. 6 Microscopique picture of the ZAT for a cuts out with surface
Vf = 560 mm/min and Pu = 5000 W

III. Modeling and Discussion

Pour cela on a utilisé la méthode statistique ANOVA avec niveau de confiance de 95% et ont a trouvé les résultats suivants (tab. 4). For better appreciate the effect of the feed rate Vf and the laser power Pu on the thickness of the ZAT, and Vf, Pu and the distance from the plane 0 (surface of the part) of the hardness of the HAZ, modeling was done using the method of experimental design [7]. For this we used the statistical method ANOVA with a confidence level of 95% and found the following results (Table 4).

Tab.4: Table ANOVA for the measurement thickness of the ZAT of C45

Source of variance	df	SS	MS	F_{test}		$F_{theoric}$
Vf	1	8075,340995	8075,341	372,7911	>	7,71
Pu	1	3533,602208	3533,60221	163,12568	>	7,71
Vf,Pu	1	1257,879052	1257,87905	58,068894	>	7,71
Error	4	86,6474	21,6618394			
TOTAL	7	12953,4696				

According to the ANOVA table (Table 5) we can see that the calculated F_{test} feed speed Vf, the laser beam power Pu and their interaction are higher $F_{theoric}$, where these three parameters affect the thickness of the HAZ and we can not ignore any parameters.

The model calculation gives the following result:

$$ZAT = 5{,}089.10^{-7}.Vf^{2{,}294-0{,}305.Ln(Pu)}.Pu^{2{,}599}$$

Tab.5: Comparaison between the exprimental resukt and the theorical resultsof the ZAT

Num of test	*Vf (mm/min)*	*Pu (W)*	*ZAT theorical (µm)*	*ZAT exprimental (µm)*	*Error*
1	560	3000	164,526	164,526	0,00%
2	560	3500	182,419	185,855	1,88%
3	560	4000	199,484	201,738	1,13%
4	560	5000	231,638	231,638	0,00%
5	1400	3000	137,973	139,245	0,92%
6	1400	3500	146,530	141,039	3,75%
7	1400	4000	154,370	150,917	2,24%
8	1400	5000	168,418	168,655	0,14%
9	2240	3000	126,062	126,062	0,00%
10	2240	3500	130,955	135,467	3,45%
11	2240	4000	135,347	141,751	4,73%
12	2240	5000	143,017	143,017	0,00%

According to the model found above, it can be concluded that the ZAT and proportional to the laser beam power (Pu) (fig.7) and inversely proportional to the feed rate (Vf) (fig.8).

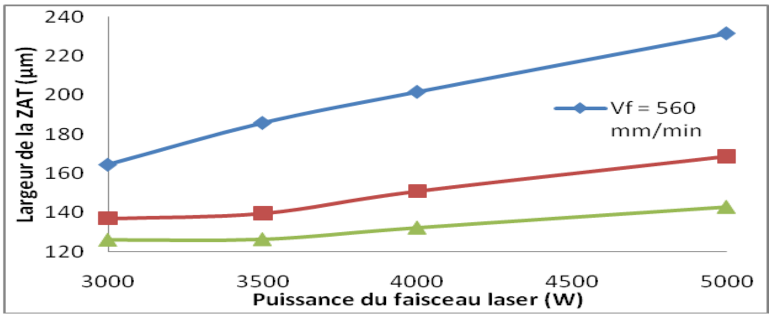

Fig.7: Effetc of the power of the laser beam Pu on the thickness of the ZAT

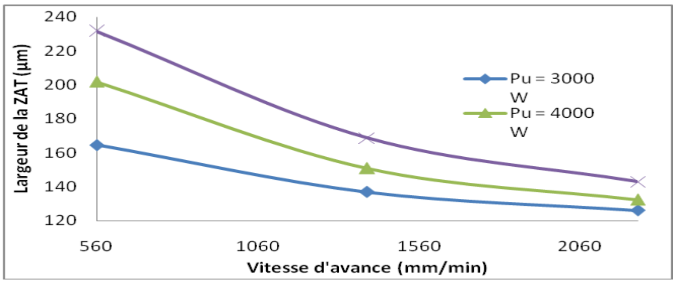

Fig .8: Effect of the speed in advance Vf on the thickness of the ZAT

This conclusion can also be seen from the curve effects (Fig. 9), which we can conclude the iso curve response of the thickness of the ZAT (Fig. 10).

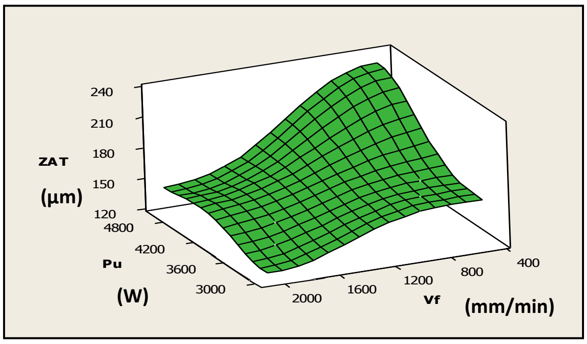

Fig.9: Curve of the effects of the speed in advance and the power of the laser Pu
on the thickness of the ZAT

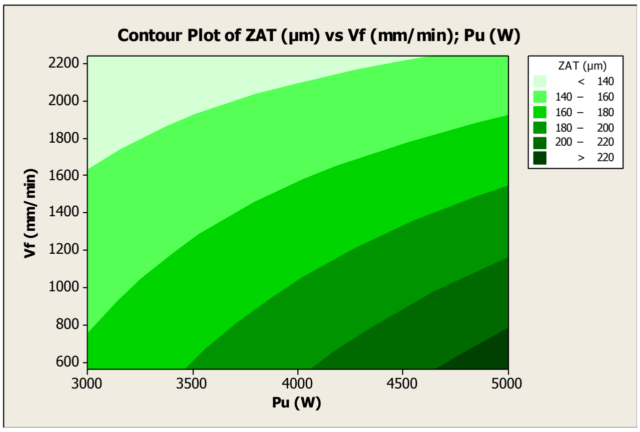

Fig.10: Curve iso answer thickness of the ZAT

I-2 Hard facing

The Hardness is usually defined as resistance of the material resiliently stressed. It is considered one of the most important properties of metals, mainly because the hardness test is a very simple test to drive though included some complicated phenomena such as plastic multiaxial behavior. In this study we focused only on the hardness in the HAZ only. The microhardness measurements were performed with the measuring device: Testwell.

Measurement type: Vickers hardness at a load of 50g.

Hold time (Duel time) = 10.

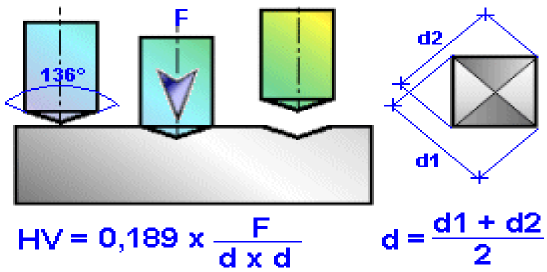

Fig.11 : Hardness Test.

The penetration is a straight pyramid with a square base and with an apex angle of 136 ° under a load F = 0.5 N. Measuring the diagonal "*d*" of the footprint.

The test is performed at room temperature; the load is applied gradually and steadily until the selected force is reached. The holding time of the load is 10 seconds.

The impression obtained has a shape of a pyramid with a square base (Fig.11).

A light spot appears on an observation screen of square shape (base of the pyramid).

It takes the average of the two diagonals of the impression: d, and calculates the Vickers hardness (HV50) in the form:

$$HV_{50} = 0{,}1891.\frac{F}{d^2}$$

Found below (Table 6) the results obtained under extreme conditions during the hardness measurement made with the device of micro hardness.

Tab.6: Measurements of hardness according to the parameters of cut and surface's depth

Num	Vf (mm/min)	Pu (W)	D (µm)	Hardness (VH)
1	560	3000	10	204
2	2240	3000	10	197
3	560	5000	10	231
4	2240	5000	10	218
5	560	3000	510	187
6	2240	3000	510	175
7	560	5000	510	203
8	2240	5000	510	189

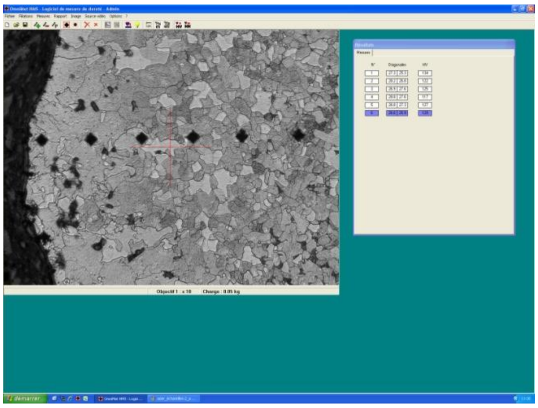

Fig.12: Print of the Micro hardness of the various zone Constituting the termicallv affected zone.

Modeling and discussion:

For better appreciate the effect of the feed rate Vf and the laser power Pu on the thickness of the ZAT, and Vf, Pu and the distance from the plane 0 (surface part) of the hardness of the ZAT, modeling was done using the method of experimental design [7]. For this we used the statistical method ANOVA with a confidence level of 95% and found the following results (Table 4).

Tab.7: ANOVA Table (Hardness of C45 steel)

Source of variance	df	SS	MS	F_{test}	$F_{theorical}$
Vf	1	1088,297858	1088,29786	2,0749306	5,32
Pu	1	3092,596658	3092,59666	5,8962934	5,32
D	1	4550,58	4550,58	8,6760602	5,32
Vf, Pu	1	24,808968	24,808968	0,0473004	5,32
Vf, D	1	10,829858	10,829858	0,020648	5,32
Pu, D	1	150,580658	150,580658	0,2870946	5,32
Vf, Pu, D	1	12,280968	12,280968	0,0234147	5,32
Error	8	4195,9875	524,498436		
TOTAL	7	13125,96245			

The ANOVA table and the Fisher test shows that a significant level of 5%. $F_{calculated}$ for Pu and D are higher $F_{theorical}$ so they are meaningful answer. But $F_{calculated}$ of Vf is less than $F_{theorical}$ but it is not negligible, so Vf is quite significant influence on the response. On all interactions, $F_{calculated}$ shows that they can be ignored and do not affect the response. The model calculation gives the following result:

$$Dureté = 63,45.Vf^{-0,042}.Pu^{0,1901}.P^{-0,0302}$$

Tab.8: Comparaison between exprimental results and theorical results of hardness

Num of test	*Vf (mm/min)*	*Pu (W)*	*D (µm)*	*Theorical hardness(VH)*	*Exprimental hardness (VH)*	*Error*
1	560	3000	10	209,888	204	3%
2	560	3500	10	215,4493	214,5	0%
3	560	4000	10	220,3856	223,5	1%
4	560	5000	10	228,8884	231	1%
5	1400	3000	10	200,6489	205,2	2%
6	1400	3500	10	205,9653	210	2%
7	1400	4000	10	210,6843	220,65	5%
8	1400	5000	10	218,8128	225,45	3%
9	2240	3000	10	196,0687	196,5	0%
10	2240	3500	10	201,2638	204	1%
11	2240	4000	10	205,8751	211,11	3%
12	2240	5000	10	213,818	217,5	2%

1	560	3000	210	191,8503	197,25	3%
2	560	3500	210	196,9336	202,5	3%
3	560	4000	210	201,4457	207	3%
4	560	5000	210	209,2178	207,45	1%
5	1400	3000	210	183,4052	191,05	4%
6	1400	3500	210	188,2647	196,5	4%
7	1400	4000	210	192,5782	202,5	5%
8	1400	5000	210	200,0081	209,7	5%
9	2240	3000	210	179,2186	178,95	0%
10	2240	3500	210	183,9672	187,5	2%
11	2240	4000	210	188,1822	191,22	2%
12	2240	5000	210	195,4426	192	2%
1	560	3000	110	195,547	200,7	3%
2	560	3500	110	200,7282	211,5	5%
3	560	4000	110	205,3273	217,5	6%
4	560	5000	110	213,2491	226,5	6%
5	1400	3000	110	186,9391	192,22	2%
6	1400	3500	110	191,8923	202,5	6%
7	1400	4000	110	196,2889	208,95	6%
8	1400	5000	110	203,862	207,95	2%
9	2240	3000	110	182,6718	187,5	3%
10	2240	3500	110	187,512	195	4%
11	2240	4000	110	191,8082	191,65	0%
12	2240	5000	110	199,2084	202,95	2%

According to the model found above, it can be concluded that the HAZ and proportional to the laser beam power (Pu) and inversely proportional to the feed rate (Vf) and the depth from the surface (D) (Fig.13). This conclusion can be seen from curve effects (Fig. 14), where one can conclude Iso curve responses hardness (fig.15, fig.16, fig.17).

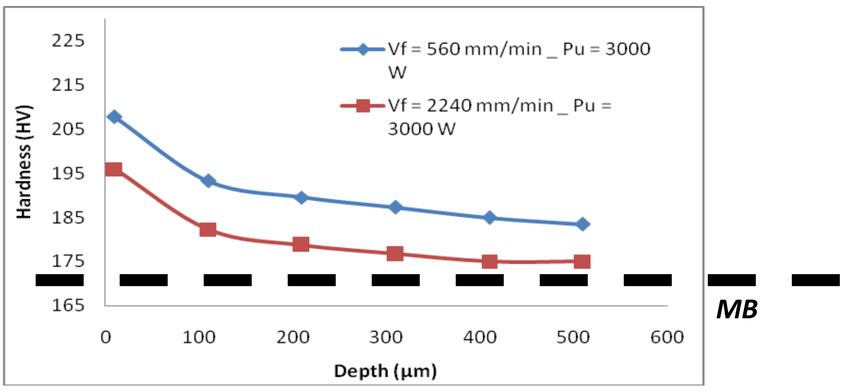

Fig.13: Evolution of the hardness of the steel C45 according to the depth D

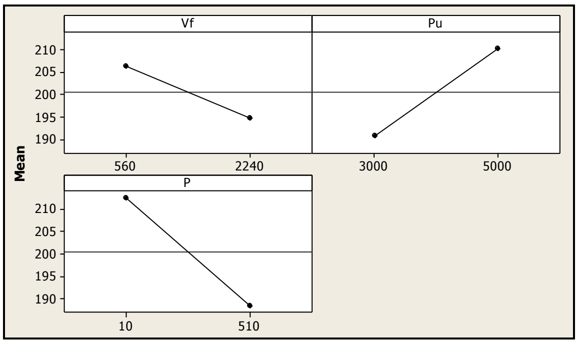

Fig.14: Effects of the speed in advance Vf and the power of the laser Pu and the depth D on hardness of C45

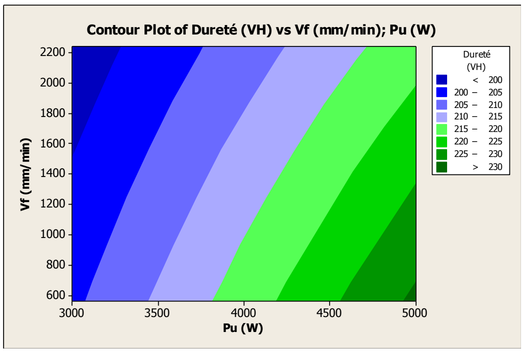

Fig.15: Iso response curve hardness according to the speed in advance Vf and the power of the laser beam Pu (D = 10µm)

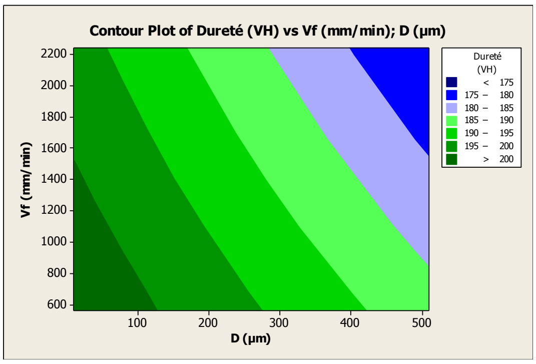

Fig.16: Iso response curve hardness versus the depth from the surface D and the laser beam power Pu (Vf = 560 mm / min)

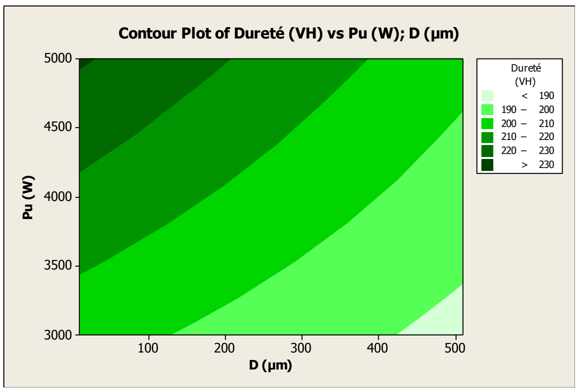

Fig.17: Iso response curve as a function of the hardness feedrate Vf and the depth from the surface D (Pu = 3000 W)

IV. Conclusion:

After CO2 laser cutting of steel C45, there is a ZAT heat that appears undergoing metallurgical and physical changes important this area is under the influence directly:

- The speed in advance :
  - Is proportional to the thickness of the ZAT.
  - Is inversely proportional to the hardness of the ZAT.

- The Laser's power
  - - It is proportional to the thickness of the ZAT.
  - - It is proportional to the hardness of the ZAT.

Bibliographic reference:

[1] Neila Jebbari, Mohamed Mondher Jebari, Faycal Saadallah, Annie Tarrats-Saugnac, Raouf Bennaceur, Jean Paul Longuemard (2007). "Thermal affected zone obtained in machining steel XC42 by high-power continuous CO_2 laser". *Optics and Laser Technology 40 (2008) 864-873.*

[2] I.A. Choudhury, S. Shirley (2009). "Laser cutting of polymeric materials: An experimental investigation". *Optics and Laser Technology 42 (2010) 503-508.*

[3] Davim JP, Barricas N, Conceição M, Oliveira C. "Some experimental studies on CO_2 laser cutting quality of polymeric materials". *Journal of Materials Processing Technology 2008; 198 (1-3):99-104.*

[4] J. Wang, W.C.K. Wong. "CO_2 laser cutting of metallic coated sheet steels". *Journal of Materials Processing Technology 95 (1999) 164-168.*

[5] Lv. Shanjin, Wang Yang. "An investigation of pulsed laser cutting of titanium alloy sheet". *Optics and Laser in Engineering 44 (2006) 1067-1077.*

[6] B. Tirumala Rao, Rakesh Kaul, Pragya Tiwari, A.K. Nath. "Inert gas cutting of titanium sheet with pilsed mode CO_2 laser". *Optics and Laser in Engineering 43 (2005) 1330-1348.*

[7] Sivarao, T.J.S. Anand, Ammar, Shukor. "RSM Based Modeling for Surface Roughness Prediction in Laser Machining". *Inetrnational Journal of Engineering & Technology IJET-IJENS Vol: 10 No 04.*