TOUGHNESS OF 8% Cr COLD WORK TOOL STEELS AFTER VACUUM HEAT TREATING[1]

Francisco Arieta[2]
Douglas P Silva[3]
Eliana B.M. Netto[4]
W K Pannes[5]
Claudia Ernst[6]

Abstract

An AISI D2 Steel, an 8%Cr – 2,75%V P/M steel and various new generation of 8%Cr ledeburitic steels have been vacuum heat-treated together at an austentizing temperature of 1030°C, followed by a sub-zero treatment and three tempers of 02 hours each at 520°C, resulting in a 58-62 HRC hadness range, typical for applications of such steels. The toughness of steels have been evaluated via impact tests with un-notched samples. The as-annealed and tempered microstructures have evaluated via optical microscopy. The results have shown that no relationship between hardness and impact values could be found among the investigated steels instead, the chemistry and microstructures differences, in particular volume fraction and size of primary carbides played the important role to explained the impact values differences among the steels. The P/M steel with its much finer and homogeneously distributed VC primary carbides, showed much superior impact values than all ledeburitic and ingot cast steels. Among the latter, the best results were achieved with an 8%Cr with aproximately 1%C, 1.4 %Mo and 1.8V, continuously cast which showed the lowest volume fraction of small primary carbides .

Keywords: 8% Cr; Tool steel; Toughness

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[1] *Technical contibution to 62nd ABM - International Annual Congress, July 23rd to 27th, 2007, Vitória - ES – Brazil*

[2] *ABM Member, Met. Eng., PhD, Product Development & Technical Services Manager, Schmolz-Bickenbach do Brasil Ltda, Rua Robert Koch, 277 CEP 04221-060, São Paulo, Brazil. Email: f.arieta@schmolz-bickenbach.com.br;*

[3] *ABM Member, Met. Eng., MSc Marketing & Sales, Schmolz-Bickenbach do Brasil Ltda, Rua Robert Koch, 277 CEP 04221-060, São Paulo, Brazil. Email: d.silva@schmolz-bickenbach.com.br;*

[4] *ABM Board Director Member, Met. Eng., MSc, Metallurgical Technical Centre Manager,* Bodycote Brasimet Processamento Térmico S/A, *Av. Nações Unidas , 21476, CEP 04795-912 São Paulo SP, Brazil. Email: eliana.netto@bodycote.com*

[5] *Deutsche Edelstahlwerke GmbH, Technical Services Dept.,Schmolz & Bickenbach Group, Aue Str. 4, D-58452 Witten, Germany, wolfgang.pannes@ewk-stahl.com ;*

[6] *Deutsche Edelstahlwerke GmbH, R&D Dept., Schmolz & Bickenbach Group, Aue Str. 4, D-58452 Witten, Germany, claudia.ernst@ewk-stahl.com*

1 Introduction

The AISI D2 or DIN WNr.1.2379 tool steel (≈1. 55%C 12% Cr 0.9% Mo 0.9%V) is still the most popular ledeburitic steel for cold work tools applications where high wear resistance and a moderate toughness are required. More recently, however, a new generation of 1%C - 8%Cr based cold work steels has been developed [1-3] and due to their better balance of carbon and carbide forming elements, in particular Mo and V, better homogeneity, size and distribution of second phase particles and improved re-melting techniques such as ESR (electro-slag refining) or VAR (vacuum arc refining) processes has led to a cold work steel with much better toughness and similar wear resistance than the original D2 steels. As a result, several 8%Cr ledeburitic steels have developed and are now available in the market. Nevertheless, the influence of different chemistries, microstructures and hardness after heat treatment on toughness for these 8%Cr have not yet compared. This work is aimed at comparing the toughness of several 8%Cr ledeburitc steels which will fullfil the following chemical composition range on carbon and carbide forming elements :

C= 1,00 ± 0,20; Cr= 8,0 ± 0,50; Mo= 2,0 ± 0,5; V= 1,0 ± 0,5; Nb ≤ 0,50 ± 0,40

2 Experimental Procedure: Materials and Methods

Materials:

Samples of 100 mm round and 100 mm long pieces, cut from standard hot rolled and annealed bars, were used in this investigation. The chemical analysis carried out investigated steels might be seen in Table 1 :

Table 1: Chemical Composition (weight %) of the steels investigated

Steel	%C	%Cr	%Mo	%V	%Nb	%Ti	%Mn	%Si	%P	%S	Obs
A	1,51	10,89	0,60	0,79	0,03	0,003	0,37	0,34	0.015	0,007	Continously Cast
B	1,23	8,53	2,46	1,28	0,56	0,013	0,37	0,94	0,023	<0,002	Ingot cast + ESR
C	0,96	7,67	2,50	0,54	0,02	0,004	0,50	0,86	0,016	<0,002	Ingot cast + ESR
D	1,15	7,99	2,09	0,42	0,86	0,012	0,32	0,88	0,013	<0,002	Ingot cast + ESR
E	0,99	7,57	1,43	1,79	0,04	0,004	0,35	1,05	0,019	0,007	Continously Cast
F	0,89	7,74	2,49	0,59	0,03	0,005	0,52	0,91	0,022	0,006	Ingot cast
G	0,85	8,09	2,04	0,53	0,16	0,007	0,45	0,91	0,029	0.007	Ingot cast
H	0,85	7,78	1,29	2,95	0,09	0,006	0,40	0,87	0,016	0,013	P/M

Notes:

- Steel A shows the classic composition of a D2, ledeburitic steel, with its aproximately 11% of Cr, 1,50% C and about 1% V and will be used for comparison reasons

-Steel B is a ESR steel, and has the highest C and Cr all 8%Cr investigated steels, one the highest Mo contents and an intermediate Nb content;

-Steel C is ESR steel, has approximately similar Mo but much lower C and V contents than Steel A and no Nb content;

-Steel D is ESR, has the highest Nb of all steels, higher C and Cr and lower

Mo contents than Steel C;

-Steel E is a continuously cast steel and has similar C and Cr contents of steel C but significantly lower Mo and higher V contents;

-Steel F is very similar to steel C but with a lower C content;

-Steel G has slightly lower C and V contents, slightly higher Cr content, higher Mo content than steel F and, a small addition of Nb;

-Steel H is a P/M steel with a lower slightly lower C, similar Cr content, lower Mo content and much higher V content , the highest content of all investigated steels and will be also used for comparison reasons;

- the content of Mn, Si, P, S are nearly the same for all steels.

Impact Sample Geometry and Testing Procedure:

In order to avoid the usual low values of absorbed energy and the consequently low accuracy of results when Charpy “V” notched samples are used for heat treated of cold work tool steels, other impact sample geometry was chosen. In USA the “C” notched sample is normally whereas in Europe un-notched are more often used. Furthermore, due to un voidable eutectic carbide banding which causes significant drop in the absorbed energy values when samples are taken from perpendicular to the rolling direction, only samples taken from the longitudinal direction were chosen to be tested. Thus, longitudinal and un notched samples, 7 x 10 x 55 mm were prepared according to the Stahl-Eisen-Prufblatter (SEP 1314) German Standard. In order to avoid any stress raisers on a as-milled surface al samples were ground after machining and the following accuracy was aimed : 7,0±0,1 x 10±0,1 x 55 ±1 mm; adjacent sides 90 degrees ± 10 minutes and surface finish $R_a \leq 0,5$ μm

All samples were numerically identified on the top of the 7 x 10 mm faces and at least 03 samples were used for each material using a 300 J Shimadzu impact test machine . All tests will be carried out at room temperature of 20±1^{o}C .

Heat Treatment Procedure:

A 10 bar Ipsen vacuum furnace from Brasimet’s facilities in São Paulo, Brazil, has been used as heat treating media for all investigated steels. The samples have been loaded at the same time and at the furnace inside position and the temperature and time were continously computer monitored . Three pre-heatings at 600C, 850 and 980.ºC with holding times of 15, 39 and 17 minutes, respectively. When the temperature reached 1030ºC, the samples were held for 36 minutes after which a 10 atm N_2 gas quenching was applied . After which a sub-zero treatment followed by 03 tempers of 02 hours each at 520ºC were carried out.

Metallography

Optical metallography which volume fraction of carbides measurements of the as-received (annealed) and after heat treatment samples, together hardness measurements before and after heat treatment, have been used to analyze the microstructure of all samples.

3 RESULTS AND DISCUSSION

The surface roughness of all samples in both faces 7 x 55 and 10 x 55 mm showed, after grinding, an average value of $R_a = 0{,}35 \pm 0{,}12$ mm, which is well within the required roughness. After the vacuum heat treatment the average value did not change significantly.

The microstructures of all steels in the as-received and annealed condition are shown in Figure1 at X 200 of magnification whereas in Figure 2 can be seen the microstructures of the same after the third temper. Comparing both figures it is observed that the large, as-annealed carbides, remained out of solution after the austenitizing, quenching and tempering heat treatment procedure. Some striking figures might be seen in those figures. First of all, it was very surprising to observe that the steel A which is a D2 steel, showed much finer primary carbides than normally expected for this steel under conventionally ingot casting. This steel, however, has been continuously cast produced. Steel H, the P/M steel , as expected, shows the presence of the finest particles of all steels. Finally, for the remaining steels (B to G), although their primary carbides sizes lie right between the steel A (D2) and H (P/M) steels, there is quite remarkbly differences among the carbide sizes, shape and distribution. The total volume fraction of primary carbides was measured in least in 03 areas and the results are shown in Table 2. The results show that Steel A, B and D showed the largest volume fraction when compared with the other steels, in particular Steel E and the P/M steel which showed the smallest volume fraction of carbides.

The hardness of all samples before (as-annealed) and after the heat treatment (quenched and tempered and sub-zero treatment) are shown in Table 3. The accuracy of the values is $\pm 0{,}5$ HRC. Apart from the P/M steel H and the AISI D2 steel A which showed a lower hardness 58 HRC , and the A steel with its higher C content which showed a hardness of about 63 HRC, all the other samples showed hardness within the range of 60-62 HRC which is the range of hardness most used for these cold work 8% Cr ledeburitic steels in various applications such as forming, blanking, piercing, slitting, thread rolling, etc. Under normal both abrasive and adhesive wear conditions such small hardness difference cannot be expected to influence the wear performance drastically but instead, the type, hardness, volume fraction and distribution of carbides must will much more important role.

The microstructure of the samples after the third temper shows a tempered martensite matrix, with no sign of retained austenite although only by a fine x-ray diffraction analysis could be used to a deeper investigation on this matter.

The results of impact test for all investigated steels are shown in Table 4 and Figure 4. From Figure 4 it is clearly observed the outstanding high absorbed impact energy obtained with steel H which is obtained from powder metallurgy (P/M) route. When the impact values were plotted against the hardness for all investigated steels and shown in Figure 3, although a good polimonial fiiting is found, it has no metallurgical meaning. For instance, the increase in toughness cannot be explained by the slightly lower hardness (58 HRC) of the P/M steel when compared with the conventional D2 (or steel A, 58 HRC) or even the other 8% Cr steels with hardness in the range of 60-62 HRC . Such difference in toughness is due to the much finer microstructure of the P/M steel when compared with other steels (A to G) which have all been ingot solidified. It is well known that in conventionally ingot cast steels, likewise in any similar slow cooling rate solidification process, carbides precipitate from the melt, during solidification. They form at the solidification front, during crystallization and agglomerate at the grain boundaries, between adjacent steel grains so that discontinous cellular network of large primary carbides is created and surrounds each grain, in the as-cast microstructure. Although, enhanced remelting processes (ESR), as used to produce steels B,C and D and further hot work operations such as hot rolling and forging will help to decrease and partially break up the cellular network, the basic inhomogeneity and the presence of large primary carbides (from 10 up to 30, 40 μm) of angular shape will remain in the microstructure. On the other hand with P/M tool steels , the average carbide size in much finer (2-3μm) because of the very rapid solidification time which prevents segregation or any cellular carbide network to be formed within the micron sized steel powder generated so that an uniform dispersion of fine and rounded carbides are formed throughout each powder particle. As a result, although the total carbide content is similar to a ingot of equivalent steel which slowly solidified, the carbide morphology, size and distribution is much different with the P/M steel which will lead to improved toughness values and explains the results shown in Table and Figures 4. The high impact results shown by the P/M steel corroborate with earlier work [4] when the impact properties, using “C” notch of the same P/M steel was compared steel with steel of composition similar to steel C.

On the other hand, if only the results of the ledeburitic (and non P/M) steels are considered, then it is possible to separate three groups of steels, according to their impact values:

- Group (I), with the lowest values and composed by steels A, B and D, showing impact values within the range of 15-16 J;

- Group (II) composed by steels C, F and G, showing an intermediate impact values, about 30% higher than Group (II), within the range of 20-22 J;

- Group (III) composed solely by steel E which showed impact values within the range of 24-26 J, that about 20% higher than Group (II) .

The results of Group (I) which include the conventional D2 (steel A), steels B and D, show that the toughness of the D2 steel was remarkably close to a 8%Cr steels when the latter steels have higher contents of C, Cr, Mo which produce higher hardness matrix. The results also indicate that such high hardness can be only be advantageous of applications where an AISI D2 tool does not fail by edge chipping so that extra adhesive and higher compression resistance will be advantageous with steels B and D. Otherwise, the edges are likely to chip and fail. Alternatively, the hardness of steels B and C can be further reduced and some gain in impact properties are likely to be obtained and needs to be investigated.

The results shown by Group (II) and composed by steels C, F and G indicated that all steels presented similar hardness and after the same heat treatment procedure as well as their impact properties, despite a significant carbon differences between them. The latter difference can be advantageous for steel C only when higher hardness and compression resistance are necessary and no risk of chipping is occurring.

The results shown by Group (III) , which is solely composed by steel E shows that this 8% Cr steel showed the highest toughness of the 8% Cr steels investigated. Its impact values are almost 60% higher than steel A (AISI D2), B and D steels for an average hardness of 60 HRC. Despite its lower hardness when compared with steels B and D, the better balance of C, Cr, Mo and V, of steel E, together its fine microstructure and smaller volume fraction of annealed carbides must have accounted for its high toughness together. In fact the latter needed to be investigated. An attempt has been made to correlate the total volume fraction of primary carbides and average size of annealed carbides on the impact values. No correlation has been found between the average carbide sizes and the impact values. However when the average volume fraction of the primary carbides and the impact values are plotted each other a good relationship has been found between as it might be seen in Figure 5. This figure shows that the smaller the volume fraction the higher the impact values . Thus, Steel E, which the smallest volume fraction showed the highest impact values followed by steels G, C and F whereas steels A, B, D, which showed higher volume fractions, presented the lowest impact values.

4. CONCLUSIONS

(i) The toughness of several new generation of 8% Cr ledeburitic steels, a traditional AISI D2 steel and a P/M steels has been compared in the laboratory via un-notched impact tests, after vacuum heat treatment at the same austenetizing temperature of 1030C, followed by 03 tempers and sub-zero treatment;

(ii) Within the hardness range of 58-62 HRC, obtained with the investigated steels, no correlation between hardness and toughess has been found;
(iii) The chemistry and volume fraction of primary annealed carbides accounted for the impact differences found;
(iv) The P/M steel showed by far the highest impact values and the large difference could only be explained by the much finer, homogeneousluy distributed and lower volume fraction of VC carbides;
(V) Among the ledeburitic steels, the best impact were achieved with the 8%Cr with aproximately 1%C, 1.4 %Mo and 1.8V, continuously cast which showed the lowest volume fraction of small primary carbides .

5. REFERENCES:

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Table 2: Total Volume Fraction of Primary Carbides for the investigated steels

Steel	Volume Fraction of Primary Carbides (%)
A (AISI D2)	13,9
B	12,8
C	6,2
D	9,43
E	5,04
F	6,73
G	5,7
H (P/M)	5,00

Table 3: Hardness of the investigated steels
Before (as-annealed) and After Heat Treatment

Steel	Hardness (HRC)	
	Before Heat Treatment	After Heat Treatment
A (AISI D2)	21 - 22	58
B	18 - 20	62
C	18 - 20	63
D	21	62
E	20 - 22	60
F	18 - 20	62
G	21 - 22	62
H (P/M)	21	58

Table 4: Impact Test Results for the investigated steels

Steel	Joules
A (AISI D2)	15 ± 2
B	16
C	21 ± 1,7
D	16,3 ± 1,5
E	24,7 ± 1,1
F	20 ± 2
G	22 ± 2
H (P/M)	98,3 ± 6,1

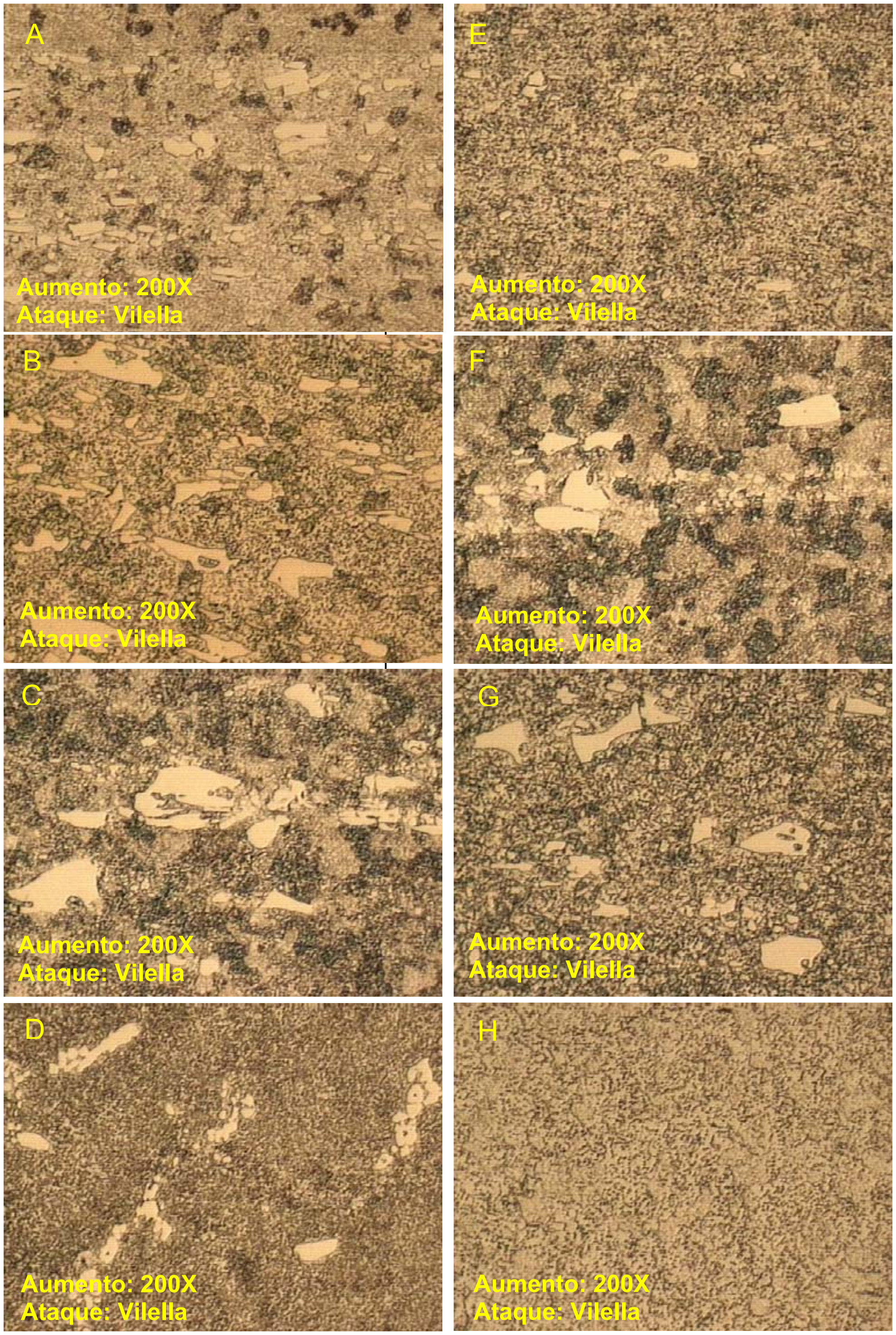

Figure 1 The Microstructures of samples A to H as-annealed

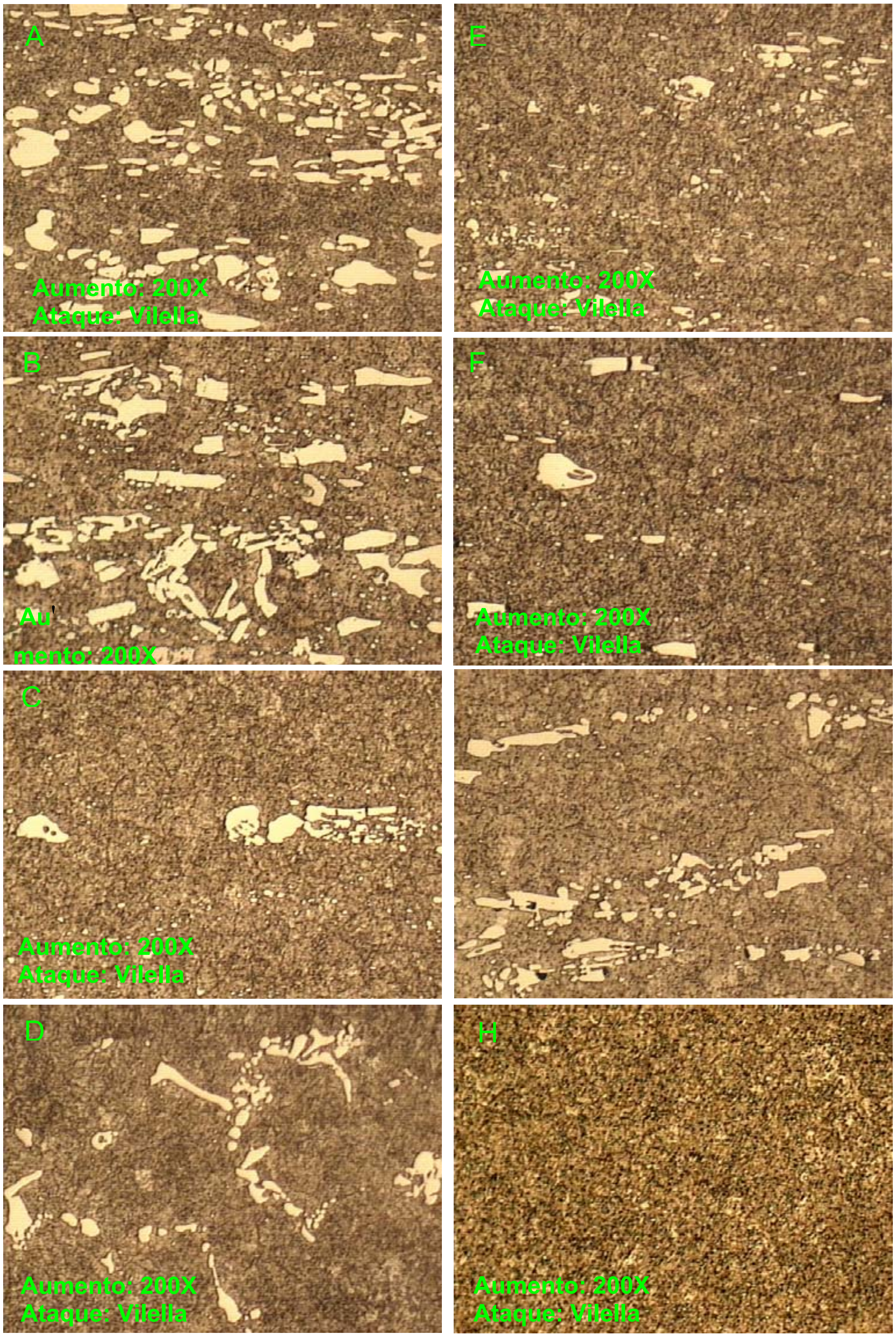

Figure 2 The Microestructure of samples A to H after the third temper and Sub-zero treatment.

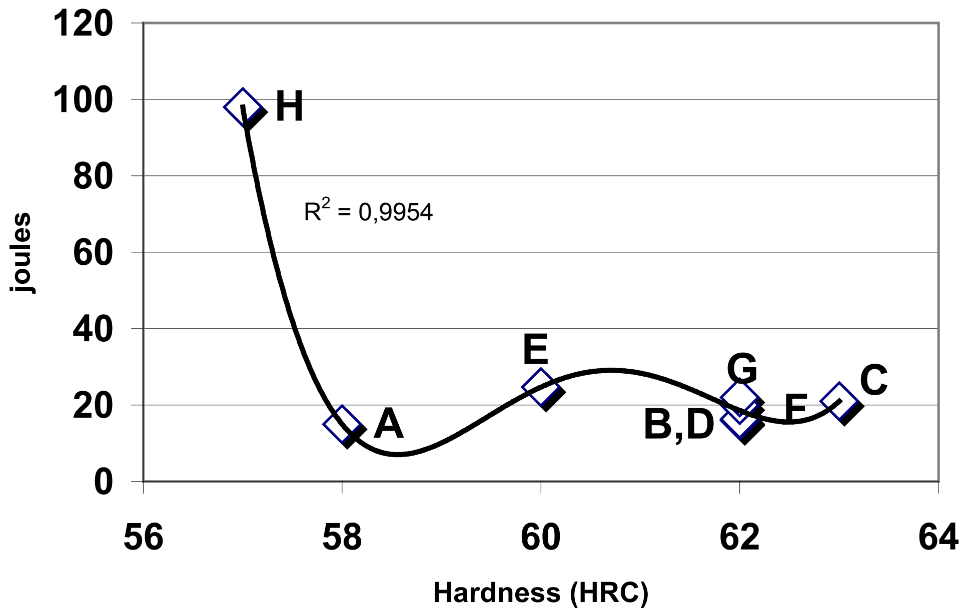

Figure 4 The Relationship between the Impact tests and hardness for all investigated

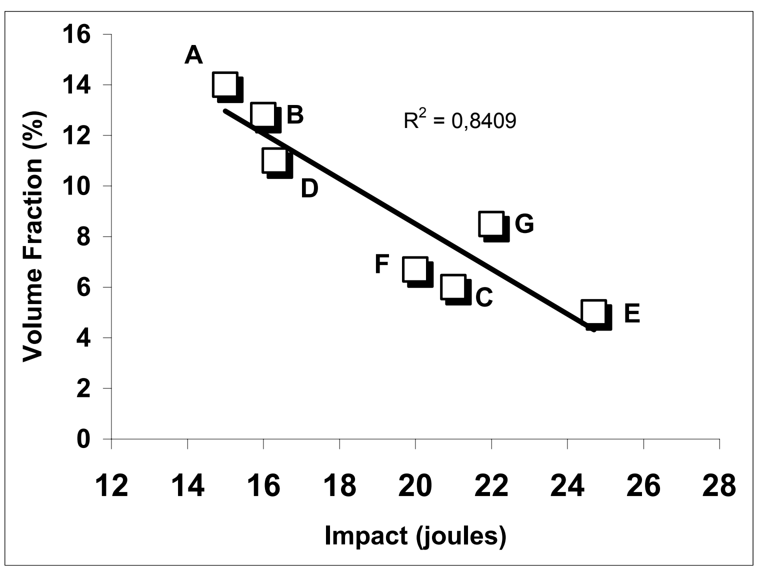

Figure 5 The Relationship between the total Volume Fraction of carbides and Impact tests for steels A to G.