IMPACT OF THE ACICULAR FERRITE ON THE CHARPY V-NOTCH TOUGHNESS OF SUBMERGED ARC WELD METAL DEPOSITS

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ABSTRACT: Submerged-arc welding (SAW) is a complex process and may be considered as a miniature casting, but because the heating temperature is higher and cooling very quickly, the final microstructure of a weld and a casting are both dendritic, but the differences are much greater than the similarities. The quality of a weld is a function of interaction of significant number of variables together with microstructural changes attendant upon welding. The microstructure produced in a weld deposits is very complex and consist of several phases and hence has pronounced effect on the strength and toughness.

The microstructure of double sided submerged-arc weld metal deposits is generally non-uniform, being composed of areas of as deposited weld metal and areas that have been reheated by subsequent pass. Acicular ferrite is one of the microstructural constituents which is most commonly formed in the weld metal deposits of low alloy steel and directly affects mechanical properties, especially toughness.

In consideration of the heterogeneity of microstructure of double sided submerged-arc weld metal deposits as dominant factor for fracture toughness, a study was oriented on the impact of the acicular ferrite microstructure on the Charpy V-notch (CVN) toughness.

The obtained results using LOM (Light Optical Microscopy), SEM (Scanning Electron Microscopy) and Charpy V-notch (CVN) toughness are presented in this study and this is an attempt to estimate the impact of the acicular ferrite microstructure on the Charpy V-notch toughness of double sided submerged-arc weld metal deposits of line pipe steel API 5L grade X65.

Key words: acicular ferrite, as-deposited microstructure, reheated microstructure, toughness.

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1. INTRODUCTION

The relationship between the microstructure and mechanical properties of the high strength low-alloy steel (HSLAS) has been the subject of considerable research. Research on the weld metal microstructures has evolved somewhat separately from the mainstream of steel research, and there are considerable problem in identifying microstructural constituents which differ in transformation mechanisms /1, 2/.
The relationship between microstructures and toughness of weld metals is very complex since a number of factors are involved and thus several researches have attempted to investigate this correlation. The microstructure of a weld metal is markedly different from that of base metal of similar composition. The difference in microstructure is not related only to chemical composition, but also to different thermal and mechanical histories of the base metal and the weld metal. The microstructure of the base metal is a result of a hot rolling operation and multiple recrystallization of the hot-worked metal. In contrast, the weld metal has an as-solidified or as deposited microstructure. This microstructure and its attendant mechanical properties are a direct result of the sequence of events that occur as the weld metal solidifies.
Acicular ferrite is one of the microstructural constituents which is most commonly observed in the weld deposit of low alloy steel and is easily differentiated from other constituents by its fine looking nature /3/. The term acicular ferrite was adopted in welding and has been generalized to describe intragranularly nucleated transformation products with a relatively wide range of morphologies /4/.
The nature and formation of acicular ferrite has been the subject of many investigations. An area that has attracted

much interest during the 1980s is the role of nonmetallic inclusion on the formation of acicular ferrite /5/. The formation of acicular ferrite is closely linked with the inclusions content of the weld metal, volume fraction, and size distribution of inclusions /6/. The acicular ferrite plates nucleate on inclusions inside the austenite grains /5, 7/.

In welding metallurgy is accepted that the morphology characterized by interwoven needles/plates, extending in several directions, that are generally nucleated intragranularly on inclusions , is termed as acicular ferrite /8/.

Double sided weld metals consist of a zone of columnar grains and a zone reheated by successive weld deposits. The reheated zone, in turn, consists of high temperature reheated zone and low temperature reheated zone. The primary zone usually consists of large columnar austenite grains at high temperatures. On the other hand , the reheated zone of a double sided weld is nominally divided into austenite coarse grained and fine grained regions, depending on the peak temperature to which they are exposed.

Impact toughness is a very important factor for weld metals and demands for improved levels of impact toughness have led to an appreciation on the complexity of the relationship between acicular ferrite microstructure and impact toughness.

Numerous investigations on the fracture toughness of weld metals have been evaluated by means of the Charpy V-notch test (CVN) and this test is still popular today because it is simple, fast and inexpensive.

2. EXPERIMENTAL PROCEDURE

Spiral line pipes Ø 813x12mm were fabricated using high strength steel coils X65 according to API 5L-American Petroleume Institute /9/, which chemical composition and mechanical properties are given in Table 1 and 2, according to the Certificate of Quality.

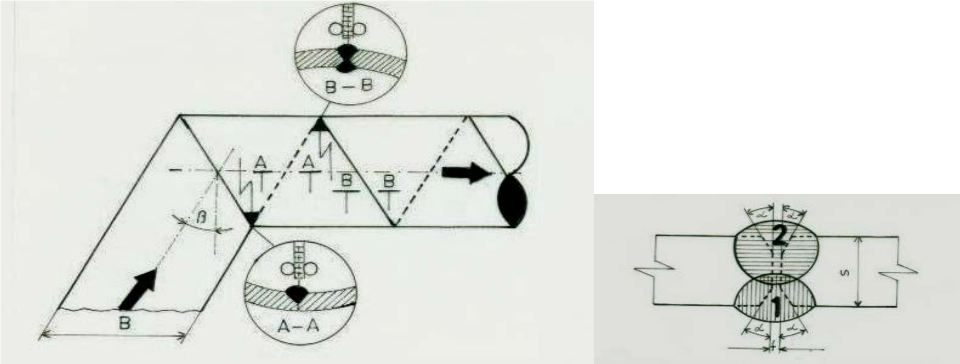
Table 1. Chemical composition of microalloyed steel coils API grade X65

Steel coils	Chemical composition wt-%					
	C	Mn	Si	P	S	V
API grade X65	0.09	1.31	0.43	0.020	0.005	0.048

Table 2. Mechanical properties of microalloyed steel coils API grade X65

Steel coils	Mechanical properties						
	Re	Rm	A	Kv_1	Kv_2	Kv_3	Kv
				ISO-V-0^oC			
	MPa		%	J			
API grade X65	549	649	23,6	132	102	143	126

Spiral line pipes Ø 813x12mm were welded in two-stage process by double sided SAW through an “X” groove configuration, according to the BLOHM+VOSS, Figure 1a with welding parameters given in Table 3.



a b

Figure 1. Double sided submerged arc welding of spiral line pipes

Table 3. Welding parameters

Line pipe	Welding parameters	
	Welding flux: LWF780	
	Welding Wire: S_2Mo	
	First pass (inside weld)-W_1	Second pass (outside weld)-W_2

	I	U	v	E	I	U	v	E
	A	V	m/min	kJ/cm	A	V	m/min	kJ/cm
Ø 813x12mm	600	28	0.8	12.6	700	30	0.8	15.7

The weld geometry of line pipes, Figure 1b does imply a considerable dilution of the weld metal (WM) by the base metal (BM) and it has been shown that microalloying elements in the base metal (MB), e.g. in this steel, vanadium (V) can be absorbed into the weld pool and has a greater influence on the microstructure of a two pass weld.

The Charpy V-notch (CVN) testing is used to measure the impact energy or notch toughness. Specimens were cut out from the double sided weld metal, perpendicular to the welding direction, as shown in Figure 2.

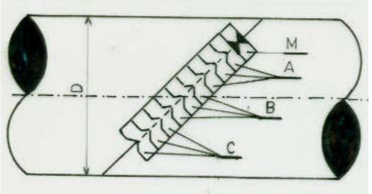


Figure 2. Sketch illustrating the orientations of the Charpy V-notch test specimens

Subsize test specimens (10x7.5x55)mm, with 2mm notch depth and 0.25mm root radius, Figure 3, were carried out with the instrumented impact machine MOHR-FEDERHAFF-LOSENHAUSEN, of 300J capacity, at the 25^{o}C , 0^{o}C and -20^{o}C, with three tests ate each temperature, specimens A, B and C.

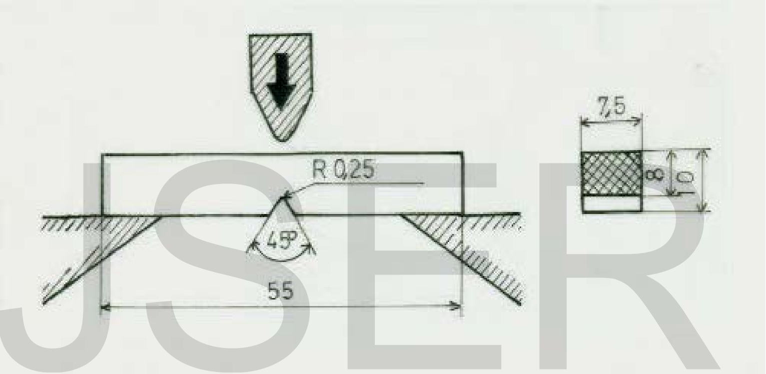


Figure 3. Shape and dimensions of the Charpy V-notch specimen

Charpy V notch (CVN) impact specimens were machined from welded joint and contained different proportion of the outside (W2) and the inside weld (W1), Figure 4, W2:W1(50:50)%, W2:W1(60:40)% and W2:W1(70:30)%. The proportion of the outside (W2) and inside (W1) weld was determined by measuring the areas of the regions (W2 and W1) included in the Charpy V-notch specimens.

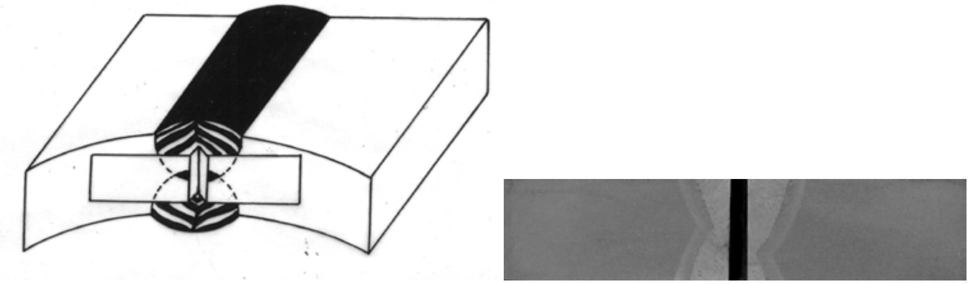


Figure 4. Details of extraction of Charpy V-notch specimens from weld metal

For the observation of macro and microstructure of double sided weld metal, metallographic specimen was extracted from the same region (specimen M). Metallographic specimen was wet ground and polished using a standard metallographic techniques and etched in 2% Nital solution, to develop the macro and microstructure. The microstructural features were observed by means of a NEOPHOT light optical microscope.

Fractured surfaces of selected Charpy V-notch specimens were examined in a scanning electron microscope (SEM). In this work, Leo 1530 SEM was used.

III. RESULTS AND DISCUSSION

The Charpy V-notch impact toughness data obtained at 25°C, 0°C and -20°C from the weld metal (WM) with different proportion of outside weld (W2) and inside weld (W1) are presented in Figure 5. It can seen from the Figure 5, general increasing tendency with increasing proportion of the outside weld (W2:W1). The proportion W2:W1 (70:30)% has the highest Charpy V-notch toughness. It is evident that the microstructure containing a high volume fraction of acicular ferrite (as deposited microstructure of the outside weld-W2) possesses a much higher Charpy V-notch toughness than the microstructure containing mainly reheated microstructural constituents (reheated microstructure of the inside weld-W1), although the latter still exhibit a reasonable toughness property.

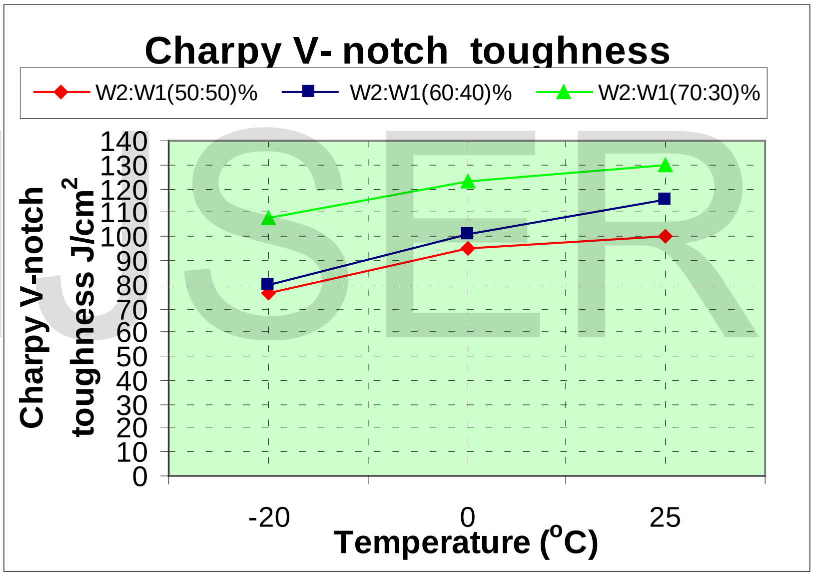


Figure 5. Charpy V-notch toughness of the weld metal with different proportion of outside (W2) and inside weld (W1)

Macrostructure in Figure 6 shows a typical cross section of two pass (double sided) line pipe weld at low magnification.

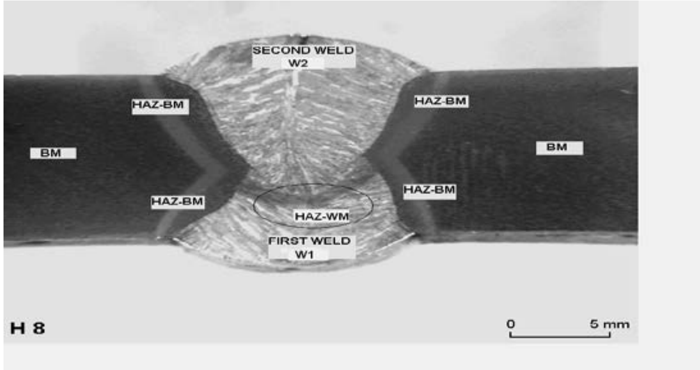
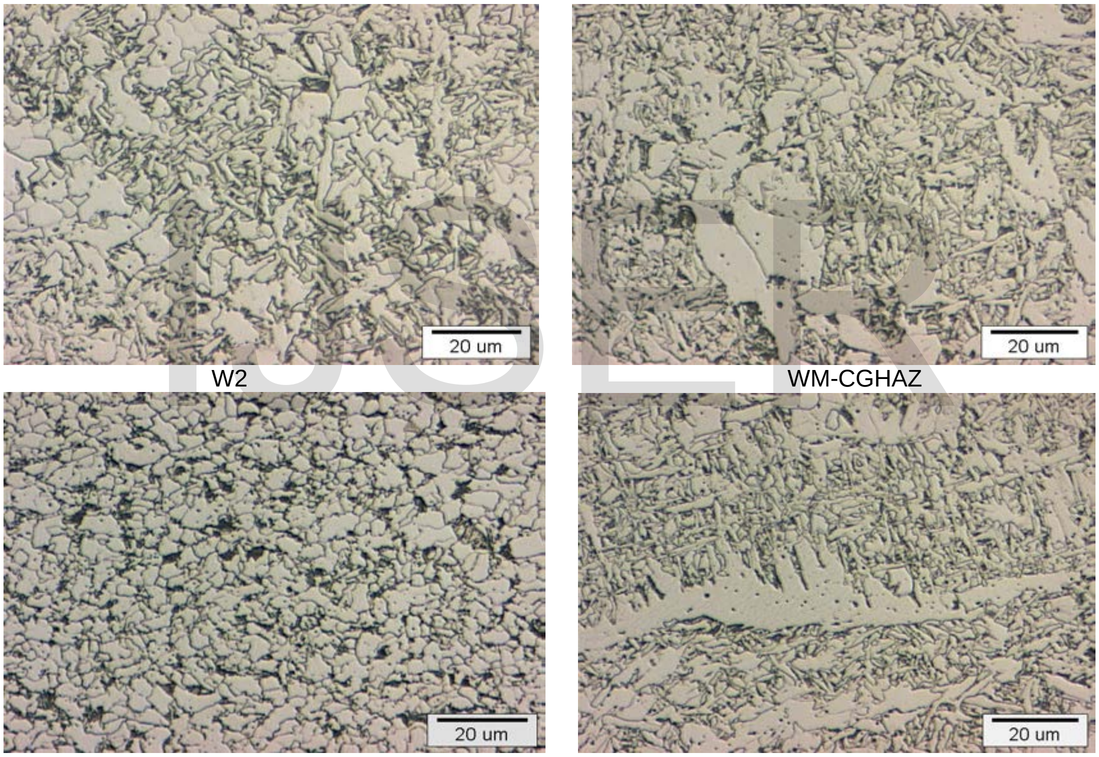


Figure 6. Macrostructure of two pass (double sided) line pipe welds

The macrostructure of a two pass (double sided) line pipe welds is generally non-uniform, being composed of areas of as deposited metal with columnar grains and areas that have been reheated by subsequent pass. Proper fusion has been achieved throughout the full thickness of the joint with good interpenetration and overlap.

The principal weld microstructures identified in this study are shown in Figure 7.



W2 WM-CGHAZ

WM-FGHAZ W1

Figure 7. Microstructures of two pass welds

The weld metal microstructure from which the Charpy V-notch specimens were taken contained as-deposited and reheated areas. Outside weld metal (W2) contain only as-deposited microstructure and in this case this microstructure consist of acicular ferrite delineated by grain boundary ferrite and small amount of polygonal ferrite. The microstructure of the inside weld (W1) was composed predominantly of acicular ferrite with small proportion of grain boundary ferrite and polygonal ferrite, formed in the grain boundaries of the prior austenite, but not in sufficient quantity to form a network or veining. The microstructure of the reheated weld metal (weld metal coarse grained heat affected zone-WM-CGHAZ), between the inside (W1) and outside (W2) weld consist of acicular ferrite, grain boundary ferrite, ferrite with second phase and polygonal ferrite. The microstructure of the reheated weld metal (weld metal fine grained heat affected zone-WM-FGHAZ) between the inside (W1) and weld metal coarse grained heat affected zone (WM-GHAZ) consist of polygonal equiaxed ferrite and pearlite. Weld metal intercritically heat affected zone-WM-ICHAZ and weld metal subcritically heat affected zone-WM-SCHAZ as small volumes within the reheated areas have not reaustenitized, and retain the classical columnar grain morphology.

Each regions of two pass weld is characterized by unique microstructure and this necessarily lead to variations in mechanical properties /10/.

The SEM (Scanning Electron Microscopy) micrographs in Figure 8 show the detailed fracture morphologies from the centre region of the fracture surfaces of an Charpy V-notch specimen. The fractured surface is fibrous with notable evidence of plastic deformation. There are numerous coarse and fine dimples, characteristic of a ductile fracture with high toughness.

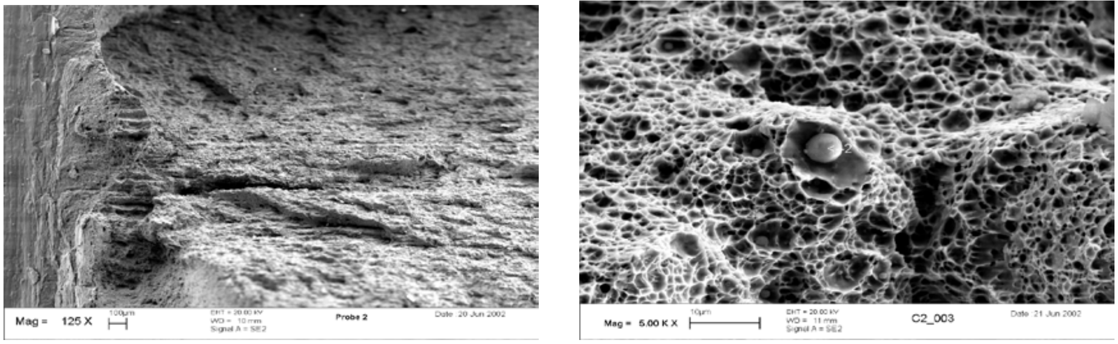


Figure 8 SEM micrograph of fractured surface of weld metal

4. CONCLUSION

Following conclusions can be drawn from the present study:

Acicular ferrite microstructure is formed within the prior austenite grains as a series of laths or plates which possess different aspect ratios of major and minor axis.

In view of our results, it may be conclusively stated that exist a general increasing tendency with increasing proportion of the outside weld (W2) with as deposited acicular ferrite microstructure.

The presence of vanadium (V) has contributed significantly to the formation of acicular ferrite in the as deposited weld metal which is the most desirable microstructural constituent in weld metal. Vanadium (V) can produce a beneficial effect in the as deposited acicular ferrite microstructure, but the situation is a little different in the reheated acicular ferrite microstructure as a result of precipitation strengthening effects.

Acicular ferrite is characterized by very good toughness due to small grain size and high angle grain boundaries which act as obstacles to cleavage propagation.

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