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Vickers Hardness Test of Steel Pipes Welded by High Frequency Induction

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The rapid development of design technology and strong market competition have prompted us to look into the field of production of steel pipes with a process that perfectly meets industrial requirements, which is high frequency (HF) induction welding, which is the most common welding process to produce steel pipes. This process is currently better known for the manufacture of pipes of different diameters at the Tube Gaz unit in Tebessa (Algeria). Among the various known destructive tests, the Vickers hardness test is used to control the pipe. This test will allow us to determine the evolution of hardness in the longitudinal and transverse directions of the welded joint. The objective of our study is based on the characterization of the processes controlling the mechanical behavior of steel pipes (type S235) with a thickness of 2.2 mm and an outside diameter of 70.70 mm, welded by HF induction. The analysis shows the existence of very diverse microstructures in the studied welded joint.

Keywords: Steel pipe, Hardness, Vickers, High frequency, Induction welding.

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1. INTRODUCTION

Tubes represent the most important semi-finished product in terms of steel production [1]. High-frequency (HF) induction welding is the most common welding process to produce steel pipes [2]. The HF induction welding process was discovered in the late 1940s, developed into reality in the 1950s, and became the main method to produce pipes in the late 1960s and 1970s [3]. Induction heating is a direct application of two fundamental laws of physics: Lenz's law and the Joule effect. By supplying an inductor with an alternating current at a given frequency (often between 50 Hz and a few hundred kHz), an electromagnetic field is created in the vicinity of this inductor. When a conductive body is immersed in these fields, it is crossed by a magnetic flux whose variations induce, according to Lenz's law, an electromotive force giving rise to eddy currents [4]. Electric resistance welded (ERW) pipes are increasingly being used in natural gas and petroleum services due to remarkable advances in fabrication, forming, welding, and other pipe manufacturing techniques. In addition, as the HF welded pipe meets the required standards, it can be economically used as a substitute for similar submerged arc welded (SAW) products or expensive seamless products under the most aggressive conditions of oil and gas production industries [5]. In the case of induction welding, the voltage is induced by the magnetic flux around the coil (without contact with the pipe) (Fig. 1) [6].

Edges of the coil material are heated up to high temperatures (Fig. 2a) and carbon along the surfaces is oxidized forming CO and CO_2. Afterwards, the heated edges are forged with external rolls and some metal is expelled (Fig. 2b) together with the oxides formed during heating [7].

At the welding point (1450 °C), the edges of an open pipe are pressed against each other by clamping rollers. Hot pressure welding follows, creating a bulk which is

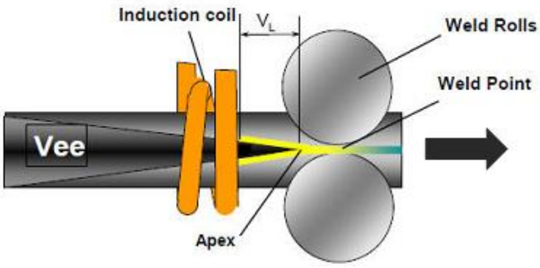

Fig. 1 – Joining of pipes by HF induction welding

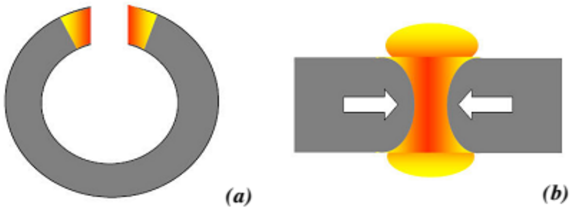

Fig. 2 – Illustration of (a) heating of the coil edges and (b) forging in HF induction welding for pipe production

removed from the outside, and possibly inside, by means of dimensions. All hardness testing methods require a good understanding of the testing process in order to obtain good results.

Hardness, which is a material control tool, is widely used to quickly determine whether the material being tested is suitable for its use. If the material is too soft, it may break due to the forces imposed on it. If it is too hard, it may crack due to brittleness of a scraper while the pipe is still hot. In some cases, welding is followed by cooling. The pipe is then calibrated, cold-formed, and finally shaped exactly.

Tubes and pipes require further examination due to their hollow shape. Obtaining the best results requires the proper choice of special techniques that can be used to improve the test method [8].

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2. MATERIAL AND EXPERIMENTAL PROCEDURE

2.1 Material

The material used for the manufacture of tubes is structural steel E 24-2 is low-carbon ferritic-pearlitic steel with a low content of Mn [9], the chemical composition of which is given in Table 1. Table 2 presents the equivalence to the standard (quality according to the new European standards) [10].

The pipe dimensions are 2.2 mm in thickness and 70.70 mm in diameter. The manufacture of a steel pipe mainly depends on the welding process, and the quality of welding is a crucial factor to determine the performance of the conveying pipeline [12].

Table 1 – Chemical composition in percentage of ERW steel pipes S235 [11]

	Chemical composition								
Component	C	Mn	Si	P	S	N	Nb	Ti	CEV
%	0.08	0.98	0.02	0.007	0.006	0.0061	0.024	0.016	0.27

Table 2 – Equivalence to the standard [10]

New European standard			Ancient national standard						
Standard	Symbol	Digital	France	Germany	Italy	RU	Spain	USA	USA
EN10025			NF A 35-501	DIN 17100	UNI 7070	BS 4360	UNE 36080	ASTM	ASTM
	S235JR S235JRGI S235JRG2	1.0037 1.0036 1.0038	E24-2 E24-2NE	St37-2 USt37-2 RSt37-2	Fe360B	40A 40B	AE235B	A283C	A570Gr33

2.2 Experimental Study

The Vickers method is the most precise method for measuring hardness and belongs to the widest measurement range [13]. There are several variants of this test depending on the value of the applied load. For the Vickers hardness test, the principle of which is defined in Fig. 3, a blunt pyramidal diamond with a square base and 136° angle between two opposite faces is used as an indenter. It is vulnerable to impacts and therefore less suitable for use in severe conditions than a ball in the Brinell process. On the other hand, it is possible to examine harder materials. There is a priori no hardness limit measured by the Vickers hardness test [13].

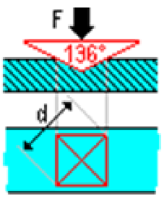

Fig. 3 – Principle of the Vickers hardness test

The force is applied for 10-15 s smoothly, up to the maximum value. It is then withdrawn. After that, the pyramid leaves an imprint of a pyramidal shape (see Fig. 4).

For loads between 100 and 1000 N, the load has no influence on the hardness measurement. For samples with a small or thin measuring surface (e.g., with a hard surface layer) or when the surface can only be slightly damaged, lower forces between 2 and 50 N are recommended. This will be referred to as the Vickers hardness test under reduced load. For loads less than 2 N, this is referred to as the Vickers microhardness test. Such a test is suitable for measuring the hardness of individual grains of a polycrystal, for example [13].

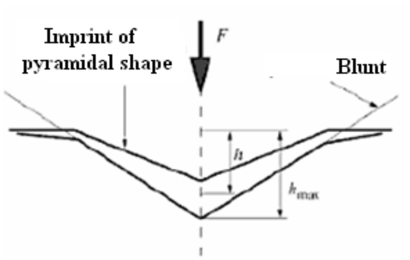

Fig.4 – Imprint of a pyramidal shape

The diagonal of the imprint is measured. The average of the two diagonals is used if the material is anisotropic. The accuracy of the measuring device (magnifying glass or projection on opaque glass) must be of the order of 1 %, corresponding to a difference in hardness of 2 %. Vickers (HV) and Brinell (HB) hardness calculations are similar. The Vickers hardness measurement is defined by:

$$HV = 2F/d^2 \cos(18°) . \qquad (2.1)$$

The Vickers hardness measurement can be performed on a convex or spherical cylindrical surface. It is then necessary, on the one hand, to maintain a good centering of the sample with respect to the axis of the indenter, and on the other hand, to carry out the correction provided by the standard according to the geometry of the indented surface [13].

2.3 Vickers Hardness in the Welded Blank

From a mechanical point of view, we distinguish three zones in the welded joint (Fig. 5): the base metal (BM), the molten zone (MZ), and the heat affected zone (HAZ). Each of these three zones has its own mechanical characteristics [14].

Fig. 6 illustrates the hardness measurement process taken directly on the welded tube (especially in the transverse case) going from MZ, HAZ to the BM.

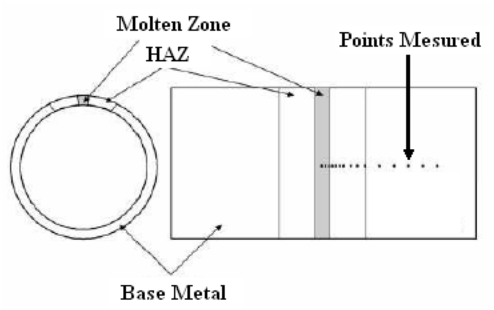

Fig. 5 – Location of Vickers hardness measurement [15]

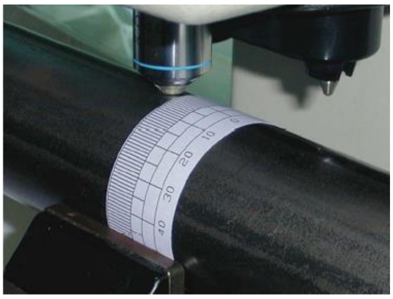

Fig. 6 – Principe of the Vickers hardness test for pipe [15]

3. RESULTS AND DISCUSSION

3.1 Hardness in the Longitudinal Direction

We show in Fig. 7 the hardness values measured in different zones of the welded pipe (in the case of the longitudinal direction). The hardness curves are presented for each zone: MZ, HAZ and BM.

It can be seen a slight increase in hardness in HAZ compared to BM: the hardness measured in BM is between 106 and 126 Hv, while in MZ, it is between 196 and 220 Hv. The hardness measured in HAZ is between 136 and 155 Hv. This is due to hot mechanical forging and residual stresses resulting from local plastic deformations, and especially to the grain size.

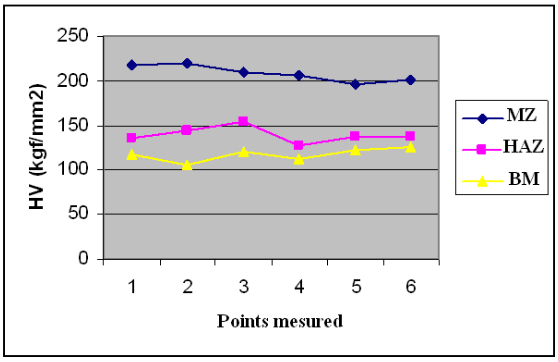

Fig. 7 – Vickers hardness in the longitudinal direction

3.2 Hardness in the Transverse Direction

Fig. 8 shows the Vickers hardness in the circumferential direction of a pipe with a thickness of 2.2 mm and an outside diameter of 70.70 mm. It also shows that there is an increase in hardness when crossing HAZ. The hardness measured in BM is between 110 and 142 Hv, while in MZ it is between 265 and 320 Hv. The hardness measured in HAZ is between 156 and 242 Hv.

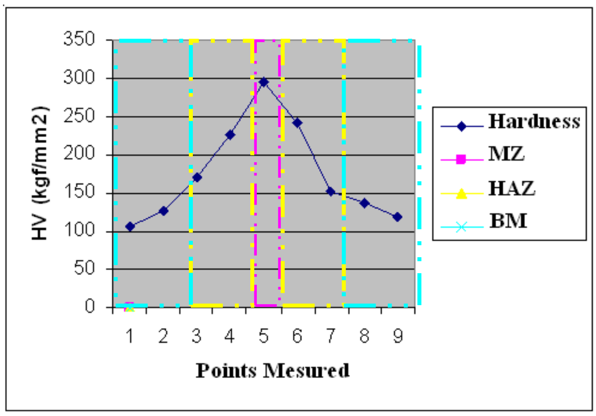

Fig. 8 – Variation of hardness in different areas of the welded blank (transverse direction)

The increase in microhardness when crossing HAZ is not regular. Nevertheless, the highest hardness is observed near MZ and is located in areas of coarse-grained HAZ. The hardness map of MZ does not allow the hardest zone to be determined. These measurements show two peaks, each corresponding to the boundary between raw MZ and reaustenitized MZ.

4. CONCLUSIONS

This analysis shows the existence of very different microstructures in the welded joint studied, apart from the nature and impurities present in the steel.

The Vickers hardness analysis shows an increase in hardness when crossing the heat affected zone (HAZ). Considering that brittle fracture is favored by areas of high hardness and large grain size, the areas which appear to be the most favorable for cleavage are coarse-grained HAZ and the molten area of solidification. This difference in microstructure leads us to carry out heat treatment to make the pipe as homogeneous as possible and avoid rupture in pressurized service.

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Випробування твердості за Віккерсом сталевих труб, зварених високочастотною індукцією

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Швидкий розвиток технології проектування та висока ринкова конкуренція спонукали нас розглянути сферу виробництва сталевих труб із процесом, який повністю відповідає промисловим вимогам, а саме високочастотним (HF) індукційним зварюванням, який є найпоширенішим процесом зварювання у виробництві сталевих труб. На даний момент цей процес більш відомий для виробництва труб різного діаметру на установці Tube Gaz в Тебесі (Алжир). Серед різних відомих руйнівних випробувань для контролю труб використовується тест на твердість за Віккерсом. Цей тест дозволяє визначити еволюцію твердості в поздовжньому та поперечному напрямках зварного з'єднання. Метою нашого дослідження є характеристика процесів, які керують механічною поведінкою сталевих труб (тип S235) товщиною 2,2 мм і зовнішнім діаметром 70,70 мм, зварених HF індукцією. Аналіз показує наявність дуже різноманітних мікроструктур у досліджуваному зварному з'єднанні.

Ключові слова: Сталева труба, Твердість, Віккерс, Висока частота, Індукційне зварювання.