

8306-011

HSLA STEEL WITH HIGH WELDABILITY AND IMPROVED CHARACTERIZATIONS OBTAINED THROUGH VACUUM HEATED LADLE REFINING TECHNIQUE

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ABSTRACT

Increasing the tensile characteristics for normalized steels commonly results in lowered weldability and toughness, because of additions of increasing content in Mn, Ni, V...

The steel described herein allows to bypass this problem, i.e. to get at the same time high yield strength (> 500 MPa) while keeping toughness and weldability comparable to that of steel with $Y.S > 460$ MPa. Two conditions are necessary to achieve this :

- optimize the chemical composition through a computerized statistical analysis, linking together all needed properties (Y.S., impact strength, weldability) and cost. The additions of alloying elements are then reduced at the lowest level necessary for the requirements.

- use a steelmaking process capable of high chemical composition accuracy. This is done by electric furnace melting followed by high vacuum heating ladle refining. Thus composition ranges obtained are very close to the aimed values.

It will be shown that it is important to choose the impurities level (S,P) and alloys additions (V) in accordance with the specification, to obtain the toughness value in plates and in HAZ, before and after postweld heat treatment.

INTRODUCTION

A major problem of steel users is to make constructions such as pressure vessels as light as possible and hence to reduce wall thicknesses. There are three types of solutions to achieve this purpose (1).

- . Quenched and tempered steels with a low carbon content (.10/.12 %) and eventually small additions of alloying elements (Ni, Cr, Mo, V, B) depending on the desired yield strength ($Y.S > 420/700$ MPa).

- Controlled-rolled plates, with a very low carbon content (.05/.10 %) and additions also depending on YS level (Mn, Mo, Nb, Ti...).

- . Normalized steels which have a medium C content (.12/.25 %) and also some alloying elements such as Mn, Ni, Mo, V...

For some applications requiring heavy plates ($t > 40$ mm), normalized steels must be preferred to controlled rolled steels to obtain the required properties through the entire thickness. Also, when large cold strain capacities or more, when hot forming is necessary, normalized steels have to be used. The additions of alloying elements, necessary to obtain the minimum strength level, can deteriorate toughness as well as weldability. So it is necessary to lower these additions as much as possible.

In Europe, the highest grade for normalized steels is that defined by the German standard SEW 089, St E 51 : $Y.S > 51$ kg/mm² (500 MPa) up to 16 mm thick plates, this value decreasing with thickness. These YS are obtained with relatively important additions of Mn, Ni, V, Cu, Ti [2] [3].

In this paper, we will demonstrate that it is possible to get steel plates according to St E 51, that have toughness and weldability properties similar to those of a lowest level, steel St E 47 ($Y.S > 47$ kg/mm² - 460 MPa), by reducing the alloying additions.

CHEMICAL ANALYSIS OPTIMIZATION - STEEL MAKING

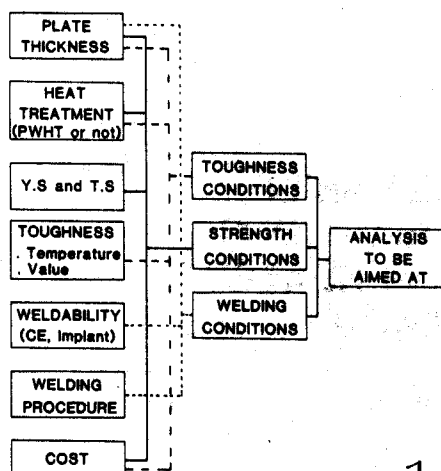
Three main conditions have to be carried out, regarding strength, toughness and weldability, and this optimization must also take care of cost. This is achieved by computer calculation with an optimization program containing several equations giving strength (YS and TS), toughness, weldability as a function of thickness, heat treatment, welding conditions and analysis alloying elements and impurities (figure 1).

This optimum composition has then to be achieved with industrial equipments; the process which is used here can be briefly described (figure 2).

- melting, oxygen blowing and desphosphorization in an electric furnace,

- desulfurization, additions and degassing in a

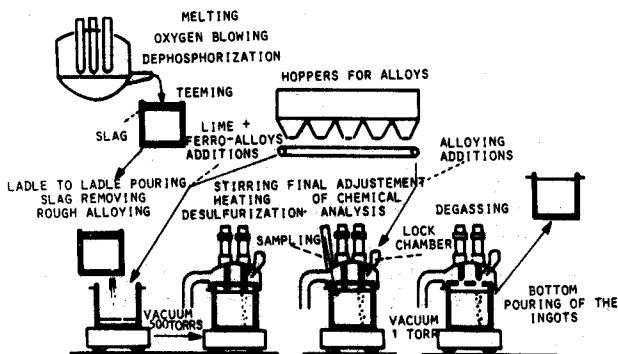
heating ladle furnace.



1.

HEATED LADLE REFINING

2.



This equipment leads to many advantages :

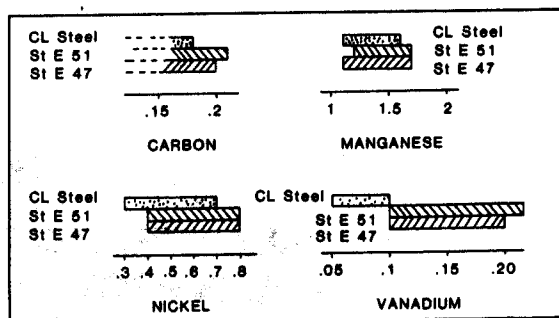
. Analytical precision : in 95 % cases, the C obtained is in the range $C_{aimed} \pm 0.010$ % . The alloying elements are added under control of a computer, using a program which chooses the additions for having a composition close to the aimed one and at the best price.

. Desulfurization : contents of 0.001 % and less are usually obtained.

. Dephosphorization : with high dephosphorization, P contents < 0.007 % are obtained.

- cleanliness : low S and O_2 level are obtained, if necessary with Ca addition, under vacuum.

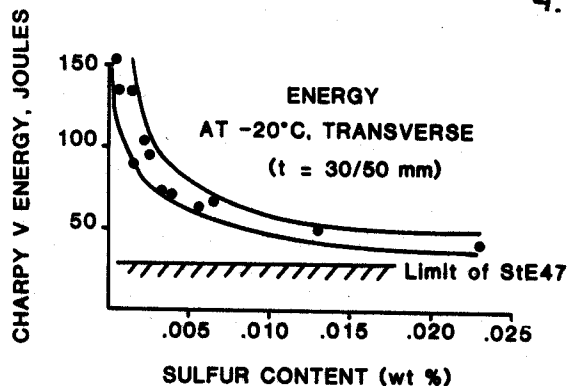
In the case of St E 51 steel, the base analysis is a C-Mn-Ni-V, and the steelmaking process associated with the optimization program allows to have alloying elements at the lowest level permitted by the standard (Mn, Ni) or below the inferior limit (V) [3] (figure 3). Concerning the carbon content, it is not only lower than that of St E 51 steels but also than that of St E 47.



3.

Concerning now the impurities, they can be obtained, as said before, at very low levels. For example, the S maximum content has to be chosen very carefully, in particular if the impact requirements are given at low temperature in the transverse direction. Figure 4, with all other elements remaining constant, shows that a low S level leads to a very high impact strength, almost equal to that obtained in the rolling direction.

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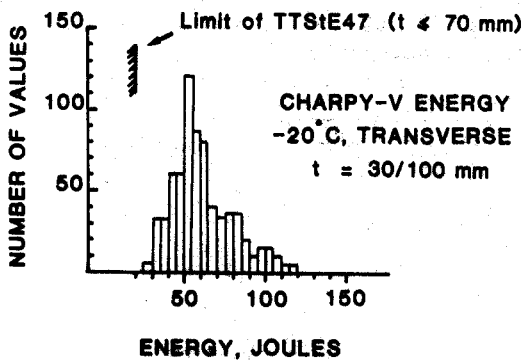
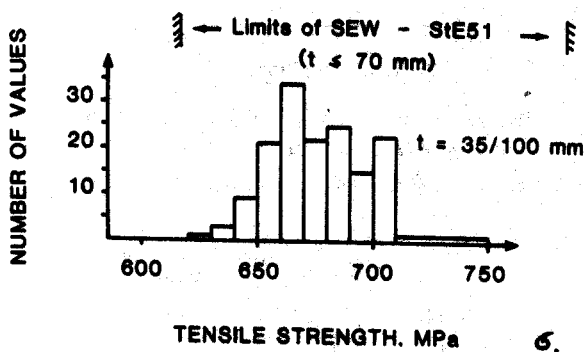
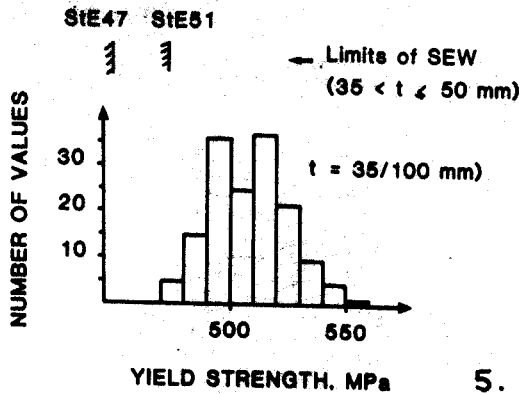


The possibility to obtain a very low P content is also very important for impact properties, but we will see later on that this concerns even more the properties in the heat affected zones of welds.

In most cases, only medium levels are required by users, for example S and P < .015 %. However, it is very important that one can achieve very low values of these impurities, for it may be necessary for special orders (low temperature applications, hydrogen embrittlement,...).

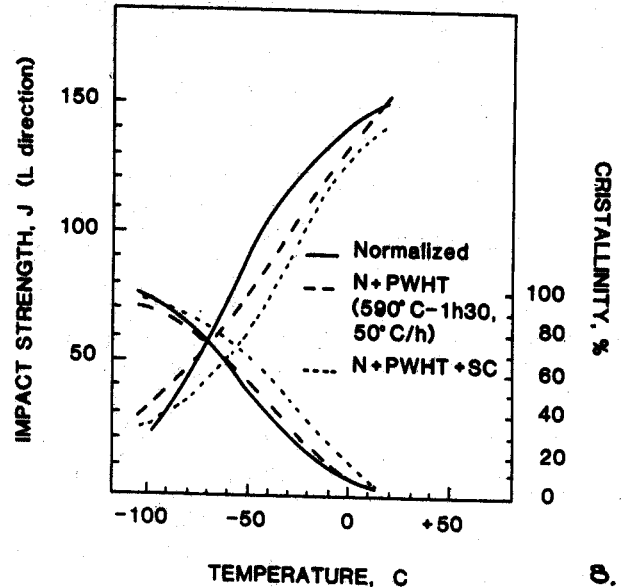
HEAT TREATMENT - MECHANICAL PROPERTIES

This C-Mn-Ni-V steel is a normalized fine-grained steel with limited additions of aluminium [4] [5]. Heat treatments are performed in very accurate furnaces and the obtained properties are in agreement with the two St E 47 and St E 51 grades. (figures 5 and 6 for yield and tensile strength for 35 to 100 mm thick plates). For impact values (figure 7) these are also in agreement with the limits of St E 47 for use at low temperature (TT St E 47). TT St E 51 does not give any value in the transverse direction at such a low temperature (only at 0°C). It must be noted that these



C	S	P	Mn	Cr	Ni	Mo	V
.160	.007	.005	1.39	.235	.460	.063	.077

Y.S = 500 MPa T.S = 680 MPa (After normalizing)



WELDABILITY

Two kinds of weldability properties have to be considered : the susceptibility to cold cracking and the mechanical properties of weldments, especially the impact strength in the heat affected zone (HAZ).

RESISTANCE TO COLD CRACKING

The most widely used test method to determine this resistance is the implant test [6]. This can be made with or without pre/post heating. All tests were made with basic electrodes.

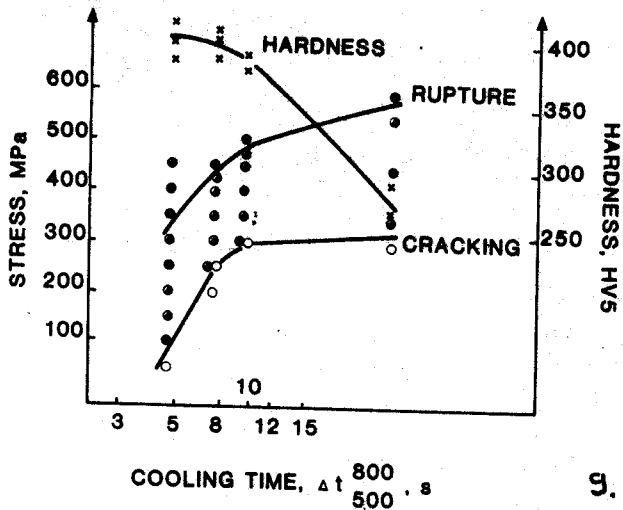
First, we made several tests without pre and post-heating, varying stress (50 to 600 MPa) and welding conditions, i.e. cooling time between 800°C and 500°C, Δt . The obtained curves for cracking and rupture are shown figure 9. If we consider the crack/no crack curve, which is the one usually used, the cracking stress is very low for a low cooling time, i.e. when the microstructure is martensite in the HAZ of the implant. So, it will not be possible to weld with a manual arc process (SMAW) without any preheating. On the other hand, with a longer cooling time (> 12 s) which is obtained by a submerged arc welding (SAW), the critical stress is about 300 MPa, hence 2/3 of yield strength.

Another series of implant tests was made, with variations of pre and postheating conditions : the

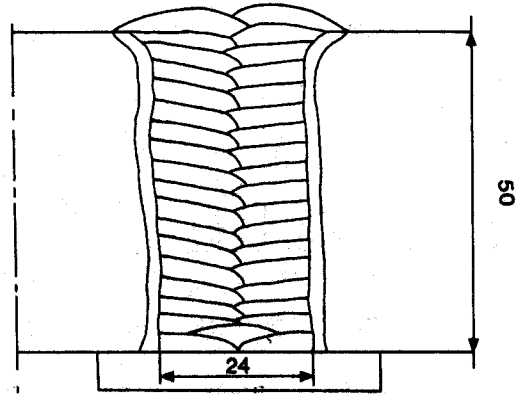
Charpy V values were obtained with a sulfur content varying between 0.0009 % and 0.007 %.

Thus, regarding both chemical analysis and mechanical properties, it appears that with additions of alloying elements lower than the limits permitted by St E 51 and St E 47 standards, strength properties in accordance with St E 51 and impacts values according to St E 47 are usually obtained.

An example of a transition curve on a 50 mm thick plate is given figure 8 after normalizing and also post weld heat treatment and a step cooling cycle. It can be seen that for such a low P content (.006 %), this steel is not susceptible to temper embrittlement. This will be further discussed.



a SAW joint on a 50 mm thick plate.



Welding conditions

Pre and Postheating : 100°C-125°C, 2h
 I = 550 A U = 30 V V = 40 cm/mn
 Wire : SAF UM40 Ø 4 mm Flux : SAF UM89

	YS MPa	TS MPa	EI%	Position of Rupture
As Welded	502	655	20.4	B.M.
PWHT 590°C-1h30 C.R.50°C/h	496	624	20.8	B.M.

temperature remains constant during the test, the time was the variable. The applied stress was $\sigma = Y.S.$

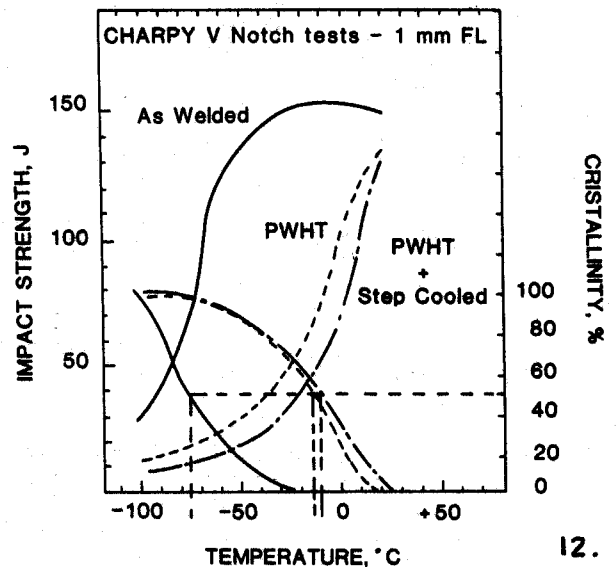
For example, we give the results for a C = .155 Mn = 1.47, Ni = 0.47, V = 0.08 plate (t = 20 mm) and a heat input of 10 KJ/cm.

100°C : no crack for time > 105 mn
 125°C : no crack for time > 15 mn
 150°C : no crack

In this condition, the welding temperature is 125°C; considering a lot of tests with variation in composition, thickness, welding process, it is possible to give the welding conditions of this C-Mn-Ni-V high strength steel : Figure 10.

WELDING PROCESS	WELD INPUT kJ/cm	PRE AND POST HEATING TEMPERATURE					Pre and Postheating	
		Equivalent thickness (mm)						
		5	10	15	20	25	> 30	
SMAW	Ø 3.2							Without
	Ø 4							50/100°C
	Ø 5							> 100°C
GMAW	15							> 125°C
	30							
SAW	20							
	30							

Impact tests were made in HAZ at 1 mm of fusion line and the results for the three previous heat treatments are given figure 12.



In the most severe conditions, the pre and post-heating temperatures are the same or lower than those given for St E 47 normal steel [7] [8].

MECHANICAL PROPERTIES IN HAZ

Weld joints have been made in different conditions, SMAW and SAW. Figure 11 gives a typical example of

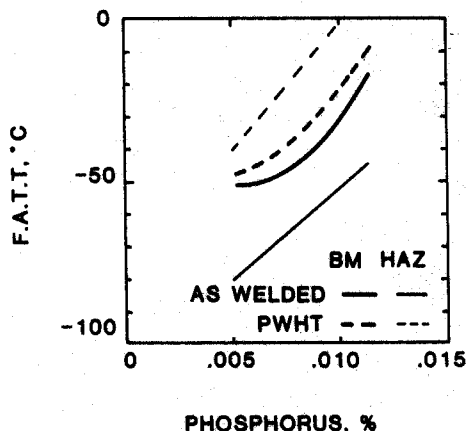
Comparing these results with figure 8, it appears:

- a slightly better toughness in the HAZ than in the base metal in as welded conditions. This is generally observed in such steels and is due to the fine low tempered bainitic structure obtained in these multipass welds.

- an embrittlement between as-welded and PWHT (50°C).

- no supplementary embrittlement with step-cooling heat treatment.

This embrittlement, can be attributed to two factors [9] : temper embrittlement and vanadium carbonitrides precipitations. Temper-embrittlement is due to segregations at grain boundaries of impurities elements such as P, Sn, As, Sb, especially P. Figure 13 shows that an important effect can be attributed to P on the lowering of HAZ toughness in the aswelded conditions, whereas there is a little effect for the base metal. Moreover, there is an important embrittlement after PWHT, but it is impossible to say if this a temper embrittlement or the result of V precipitation, because of the slow cooling after PWHT (50°C/h). However, the embrittlement is more important for a higher P content.



13.

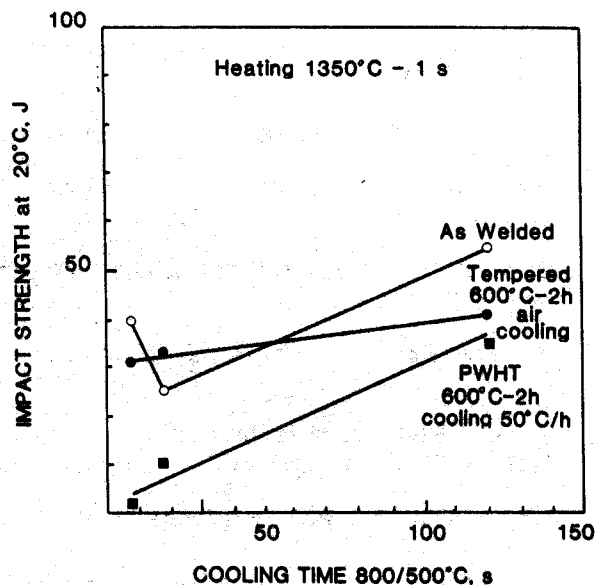
Figure 14 gives the results of impact tests after a gleeble simulation with a peak at high temperature and a steel with a quite high P content (0.015 %); this to enlarge the phenomena, and with two different cooling rates after tempering. It appears, that for a martensitic structure (low Δt , SMAW), we have only temperembrittlement, and for a bainitic one (high Δt , SAW with high input) the embrittlement is essentially due to a tempering effect, therefore to V precipitates.

In SAW multipass joints, the embrittlement is for the main part of this second type, and it will increase with an increasing V content [10] [11].

So, it is important to limit V content as well as impurities such as P, and in these conditions the impact energy after PWHT remains in agreement with the standard for base metal.

CONCLUSIONS

The increase of yield strength of normalized HSLA steels can be obtained without detrimental effect on toughness and weldability. For example it is possible to ensure a YS > 500 MPa with the



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qualities of a YS > 460 MPa steel with the following conditions :

- an optimization of chemical analysis with the aid of computer calculations based on statistical equations.

- the achievement of a chemical composition of plates very close to the aimed one, thanks to the ladle refining process. This ensures the minimal yield and tensile strength.

The impact level depends on numerous factors, especially S content. It is possible to obtain very high Charpy levels at low temperatures and in the transverse direction with a low S level. A level less than 0.001 % S can be commonly achieved, but is not always necessary. The limitation of additions : C, Mn, Ni allows a weldability equivalent to that of a lower Y.S. steel. In the most severe conditions ($t > 30$ mm, low input), the pre and post-heating temperature of the 510 MPa C-Mn-Ni-V steel will be 125°C.

Postweld heat treatments lead to a deterioration toughness due to an addition of temper embrittlement and V carbonitrides precipitation. For limiting this embrittlement low impurities level, particularly P, and a limitation of V are necessary.

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