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Study Regarding the Behavior of 12Cr 130 (W 4006) Steel for Hydro-Energetic Applications During Welding

The topic of the work consists in the research of the W4006 (12Cr 130) steel behavior during welding in order to establish the welding technology for a runner chamber of the hydraulic turbine following: testing the base material of the runner chamber, choice of welding procedure and filler materials, determination of the welded joint chemical composition, determination of the pre-heating temperature, thermal treatment applied after welding, experiments and results.

1. Runner chamber base material testing

The 12 Cr 130 (W 4006) steel, according to DIN 17400 has the following chemical composition and mechanical characteristics (table 1 and.table 2)

Table 1

C%	Mn%	Si%	Cr%
0,08 – 0,12	1,0	1,0	12,0 – 14,0

Table 2

Flow limit σ_C	Rupture strength σ_r	Elongation δ	Resistance KV	Hardness HB
daN/mm^2 30	daN/mm^2 55 - 70	% 20	DaJ/cm^2 12	HB 140 - 180

The steel W4006 is classified among the martensitic stainless steels. At the solidification of the steels with 12 – 14 % Cr şi C </ 0.15 % the ferrite is transformed during cooling into austenite that can decompose into ferrite and carbide when slow cooled, or into martensite when fast cooled. So, theses steels are self-hardening, the austenite remaining stable up to the upper martensite transformation point. The steel

with 12 – 14 % Cr , shows a good cavity and erosion strength leading to choose the steel W 4006 for performing the turbine chamber. The steel with
12 – 14 % Cr and C<0.15 [2] hardened in oil at 1000^{o}C gets the rupture strength σ_r = 140 kgf/mm^2, flow limit σ_c = 120 kgf/mm, alongation σ_5 = 8 – 9% and resilience kv = 2kgf/cm^2, due to martensite low content of carbon. These steels can also be delivered in annealed condition, when through a phase recristalization annealing at 850 – 900^{o}C can be mechanically machined.

The steel W 4006 in delivery condition is improved (hardened and annealed) and shows a ferit-martensitic structure with fine, dispersed carbides that give a good cavity and hydro-erozion strength.

2. Choice of the filler materials

In order to corectly choose the welding materials; the following criteria will be taken into account sauch as [3]:

Compatibility between the base and filler material in order to observe this condition, the correlation between the mechanical characteristics of the filler and base materials should be checked provided, the cracking tendency of the material deposited on a reference material and the correspondence between the structural characteristics should be also verified.

The assurance of the mechanical characteristics of the material deposited by welding at the level of the base material mechanical characteristics is an essential condition regarding the filler materials destined to the welding of the low alloyed and high strength carbon steels. It is not a definitory condition this is not a definitory condition for the dificulty meltable stainless steel where certain specific priorities concerning the chemical and structure strength represent a priority.

The correct interpretation and knowledge of certain mechanical characteristics influence make the correct choice of the filler material easier.

- Rupture strength and flow limit.

The conception, still well spread, that rupture strength of an electrode or other material used for welding, represents the first criterion of selection and correlation with the characteristics of the base material The conception that rupture strength of an electrode or another material for welding represents the main criterion for selecting and correlating with the characteristics of the base material is still quite spread. The choice of the base material is indicated [3] to be made considering the value of the nominal flow limit value, this one being considered as the main criterion.

- Elongation

The recent recommendations give a secondary role to the choice of the filler material depending on the elongation value. At present a welding material, due to the perfection elaborating technologies, actually provides the value of the steel elongation, at least, very appropriate to the nominal flow limit of the base and filler material.

- Resiliency

The deposited material resiliency is the characteristic mostly used most frequently for defining the tenacity of a welded joint.

The value of the filler material resiliency should be correlated with the base material resiliency so that, at a certain test temperature, the guaranteed minimum value for the deposited material rupture resiliency or energy should be higher with appreciatively 30-40I/cm^2 than the guaranteed minimum value of the base material.

The chemical composition correlation starts from a general validate principle indicating that the base and filler material should have chemical compositions of the alloying materials as appropriate as possible for a good welding compatibility and the content of sulphur and phosphorus should be as low as possible.

The correlation between the structural components and the cracking tendency of the filler material is verified only for performing certain makes of electrodes or for welding certain steels whose welding behavior is not well known. In general, this correlation is recommended to weld stainless and refractory steels as well as to choose welding materials destined to weld the high strength steels thermally treated or some new types of steel with high flow limit.

The martensite stainless steels can be welded either using a filler and base material with the same chemical composition or an austenite filler material.

The use of similar filler and base materials is difficult as the deposited materia has the tendency to crack because the austenite does not turns into ferite and carbures during cooling, but it turnes into martensite between the temperatures of upper Ms and lower Mf martensitic transformation.

That transformation of austenite into martensite produces an over saturation of hydrogen that diffuses towards defectives of the welded joint and may lead to cracks occurrence under the joint. For this reason, special measures are needed during and after welding and that leads to the choice of the filler and base materials with same chimical composition especially when the joint is exploited in a gas medium rich witf sulphur under repeated thermal shocks.

When martensite steels are welded with austenite fillers, the two materials having different dilatation coefficients, the thermal fatigue effect may occur when the joint is subject to repeated heat. Due to different dilatation and shrinkage additional stresses may occur that can generate cracks in the thermally influenced area. The austenite fillers will generate a deposited material with chemical composition different from the base material, austenite or austenite-ferite type that offers a high plasticity to the joint avoiding the cracking even at the cold welding of the small thickness plates, also preventing the hydrogen diffusing towards the base material. Basic cover electrodes are used as they have high cracking strength and a smaller quantity of hydrogen in the joint. The experiments made in the world [4] proved that it is indicated to use electrodes type 25/20 for martensite steels with 12 – 14%Cr in order to avoid the martensite within the dilution area.

In order to weld the runner chamber liner of the hydraulic turbine, made of steel W 4006 and to perform heterogene joints between the liner (W4006) and the skeleton (OL 37.1K), 25Cr20NiB electrodes are used with the following chemical composition and mechanic characteristics of the material deposited by welding. (table 3 and 4).

Table 3

C % max	Mn % max	Si % max	Cr % max	Ni %	P %	S %
0,12	0,30	1,0	24,0 – 28,0	19,0 – 22,0	max 0,025	max 0,020

Table 4

σ_r N/mm^2 (kgf/mm^2) min	σ_c N/mm^2 (kgf/mm^2) min	δ_5 % min	(KCV – kgm/cm^2) min - 185 ^{o}C	KCU2 – kgfm/cm^2 min + 20 ^{o}C
295 (30)	540 – 685 (55 -70)	30	40 (5)	100 (13)

The chemical composition determination for welding with electrodes 25Cr20Ni is performed by means of Schaffler diagram. The chemical composition of the filler and base material should be known, as depending on it, the equivalent of chrom and nickel is calculated.

The chemical composition and the mechanical characteristics of the plate W4006 used for samples are shown in table no. 4 and 5.

Table 5

C %	Mn %	Si %	P %	S %	Cr %
0,10	0,73	0,44	0,047	0,015	13,64

Table 6

Rupture strength kg f/mm^2	Flow limit kg f/mm^2	Elongation %
65	46,5	19

In order to calculate the equivalent of chromue (Cre) and nickel (Nie) the following relations were used:

Cre= Cr + Mo 0.5 Nb 1.5 Si; Nie= Ni +30C +30N +0.5Mn

For electrodes 25Cr20Ni the following values are obtained: Cre=25.11%; Nie=23.465%.

For the base material (W4006) following values are obtained :

Cre=14.3% ; Nie=3.365%.

Considering that the base material participate in proportion of 10 – 13% [5] to make up the joint, it follows that deposited material will have a pure austenitic chemical composition according to diagram Schaffler (fig. no. 1). In the other areas of the welded joint, the following components are obtained:

- austenite + ferite;
- austenite + martensite + ferite;
- martensite +ferite, in the base material.

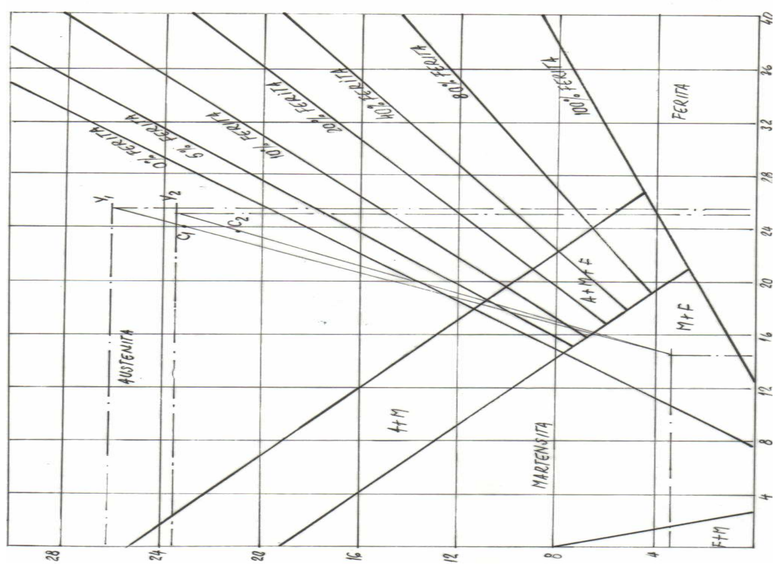

Figure 1.

For the martensite steels with 12 –14% Cr and C<-0.15% the fundamental characteristic of their weldability is that for air cooling, the austenite does not turn into ferite or even carbures but maintain itself stable up to temperature of the martensitic upper point (Ms) when the martensite transformation begins, that stops at the temperature of the martensite lower point(Mf).

In order to determine the martensitic upper point (Ms) and the martensite lower point (Mf) the following calculus relation will be used:

$$Ms = 561 - 475(C) - 33(Mn) - 17(Cr) - 17(Ni) - 21(Mo) - 11(W) - 11(Si) + 27(Nb) - 44(V) + 19(Ti)\ [^{o}C]$$

$$Mf = 210 - 362(C) - 10(Mn) - 0.5(Si) - 3.5(Ni) - 6(Cr) - 14.5(Mo) - 1(V) - 3(W) - 12(Nb) + 74(Ti)\ [^{*}C]$$

For the base material W4006 the following values results:

$$Ms = 252.56^{o}C\ ;\ Mf = 84.28^{o}C$$

In order to avoid the crack [2] the welding is recomanded to be performed with pre-heating, and the pre-heating temperature should be generally situated over the finish point of the martensite (Mf) and under the start point of the martensite transformation (Ms), so between 84.28^{o}C and 252.56^{o}C.

Also, as the material deposited with austenitic electrodes shows a sufficient plasticity, having a high coefficient of adaptability to the applied voltages, any thermal treatment for the stress eliminating is useless after welding.

3. Experiments and results

3.1. Sample pre-heating temperature checking CTS

The method relays on the practical check of certain weld joint performed on elements of the steel under discussion whose thermal severity index is well known. The method allows to reproduce the real conditions of the phenomena taking place in the weld joint.

The principle of those method consists in testing certain pre-heating temperatures theoretically or empirically defined. The check consists in examining the section of the weld joint in order to determine the structure, the cracks or microcracks in ZIT.

Sample preparation CTS

Two plates made of researched steel (W4006 are prepared for the hydraulic turbine runne chamber) at the dimensions shown in fig. 9. The contact surfaces of the two parts should be clean, lack of improvements in order not to influence the result of the test. The plates are fastened by the means of a balloon before welding

Sample welding CTS

The two plates are welded with one another only on the frontal edges in groov position, i.d. the part is inclined at 45^{o}, if the horisontal welding position is tested. The sample CTS is shown in fig. no.2.

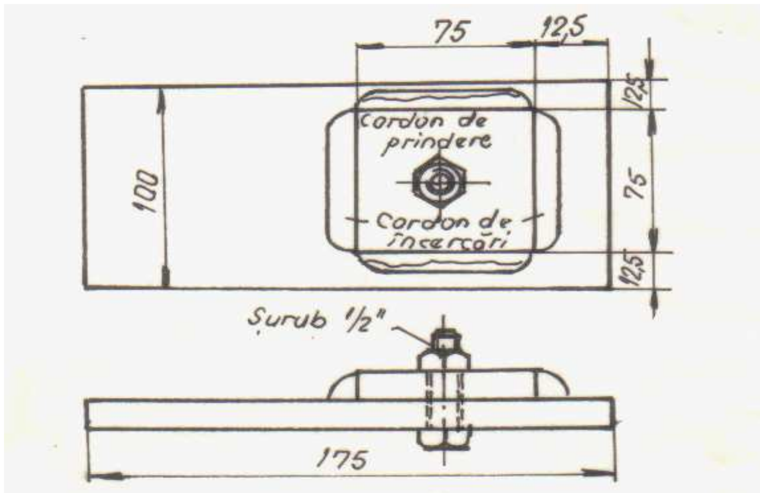

Figure 2.

Electrodes of prescribed quality and dimensions will be used. Electrodes 25Cr20Ni, 5 mm diameter were used for welding the samples CTS made of W 4006.

The pre-heating temperatures are the ones that should be tested. The test is performed at temperature intervals in order to determine the optimal pre-heating temperature were there is the guarantee of hardening structure elimination.

The welded joint could be uniformly deposited, without caves, edge burns at the maximum dimensions allowed on edges. After welding the part is cooled in environmental medium, and 24 hours later it is sectioned.

Sample examination CTS

The sample is cut by mechanical procedures (on milling machine). Midle and end sections of the welding joint are cut, which are examined by the following means of control :

- visual control;
- magna-flow control;
- macro şi microscopic control;
- control of hardness.

These tests should be made for the base material and the material deposited by welding as well as in the area thermally influenced. The pre-heating temperatures for the samples CTS were chosen taking into account the results obtained in calculus, namely 220°C and 250°C.

The samples welded CTS were performed with the following welding regime (table no. 7).

Table 7

Sample no.	Preheating temperature	Welded joint	Welding regime parameters			
			U_a	I_s	V_s	E_l
1	220	Bithermal	26	170	0,259	17070
		Trithermal	27	170	0,278	16900
2	250	Bithermal	27	170	0,275	16750
		Trithermal	26	170	0,258	17200

48 hours later after welding the samples were machined, cutting out three samples from each welded join (bithermal respectively trithermal).

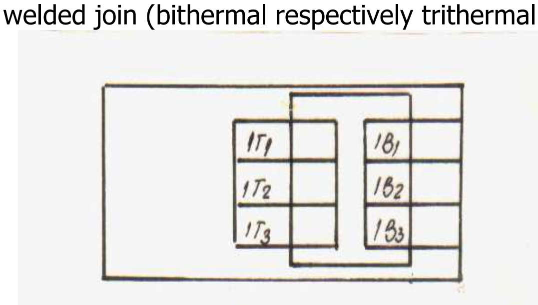

Figure 3.

After cutting out, the samples were prepared for the microstructural analysis. At the dimension of 500X no cracks were noticed within the area of the welded joint. The sample macrostructures are shown in fig. 4.

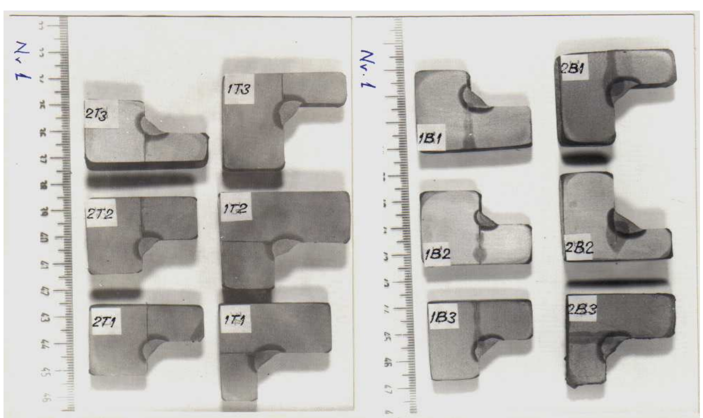

Figure 4.

The hardness HVS of the samples CTS were measured as it is shown in the sketch in fig. 5 and the values of the measures are given in the table no.8

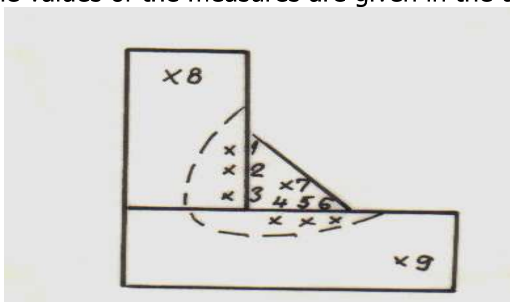

Figure 5.

It is found, by analyzing mediums of the measures of hardness in the area of transition to the samples CTS, that for the saple pre-heated at 220^{O}C, the values of the hardness exceed 350HVS. However, the occurrence of some cracks were found at the metalographic analysis in ZIT, or in M.A.

Table 8

Sample no.	Pre – heating temp.	Hardness HV5									
		1	2	3	4	5	6	Average	7	8	9
1B1	220	401	396	325	310	313	310	342,5	232	225	223
1B2	220	353	310	391	362	429	401	374,3	195	208	212
1B3	220	401	396	386	412	367	358	386,6	208	239	241
1T1	220	423	460	473	466	473	441	456	283	229	229
1T2	220	407	454	441	401	418	401	420,3	214	223	210
1T3	220	407	418	386	418	407	412	408	192	223	210
2B1	250	336	329	336	310	412	353	346	232	223	221
2B2	250	280	358	321	345	386	317	334,5	210	232	223
2B3	250	317	362	321	358	371	286	335,8	210	195	223
2T1	250	265	386	401	321	293	371	339,5	210	210	225
2T2	250	321	396	262	396	321	353	341,5	232	227	225
2T3	250	358	329	358	391	358	293	347,8	208	206	212

As for the sample pre-heated at 250^{O}C, the measures average of the hardness within the transition area do not exceed the value of 350HVS.

A structure with austenite type oriented grains are noticed, by analyzing the obtained microstructures, and the transition area is constituted of a narrow zone of austenite, while towards MB bainite formations occur. The base material is formed of a sorbite – bainite mass with finly dispersed chrome carbures inclusions.

It follows that, by analyzing the samples CTS welded at the pre-heating temperature of 250^{O}C, this pre-heating temperature is sufficient for the plate thickness of 45mm of the steel W4006.

3.2. Mechanical tests

In order to test the characteristics, a butt welded sample was performed.

The mechanical samples has the gap between parts as shown in fig. 6, the one corresponding to the chamber segments.

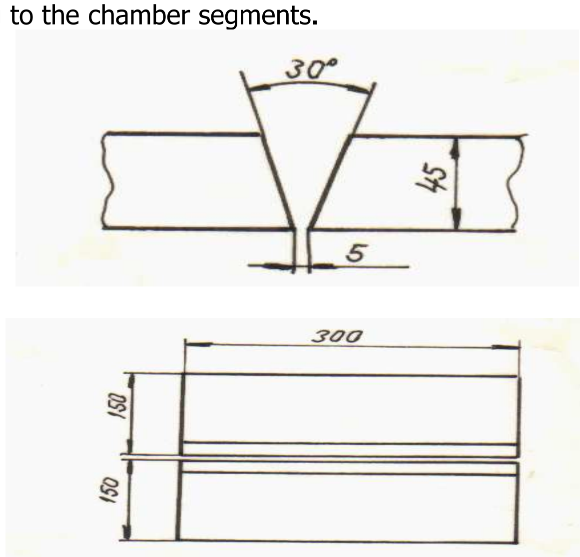

Figure 6.

The parameters of the welding regime used for these mechanical samples were as follows :

- pre-heating temperature: Tpr= 250^{O}C ;
- electrodes : E 25Cr20Ni ;
- electrode diameter : d_e= 5mm;
- welding intensity : Is= 170 A;
- welding velocity : Vs= 0.25-0.27 cm/sec ;
- liniar power: E_l= 16500- 17500J/cm.

After welding the sample was cooled in still air without thermal treatment. The results of the mechanical tests are shown in table 9.

Table 9

Rupture strength	Bending d=30	KV la -10^{o}C		
		Zr		MA
635	30^{O}	45	60	80
620	30^{O}	45	50	90

It is noticed that the the resiliancy Kv at –10^{O}C is higher than the critical value of 3.5 kgf/cm^2 in the transition area. The working temperature of the runner chamber does not reach lower values of .

It is noticed, by analysing the values of the hardness obtained on the metalographic sample (fig. 7), that generally this one is situated under 350HV5.

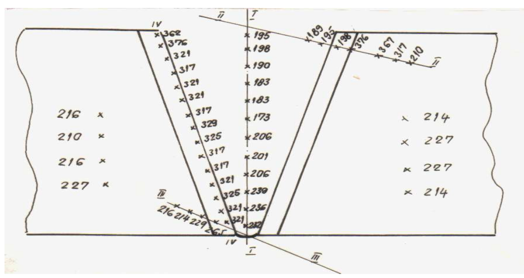

Figure 7.

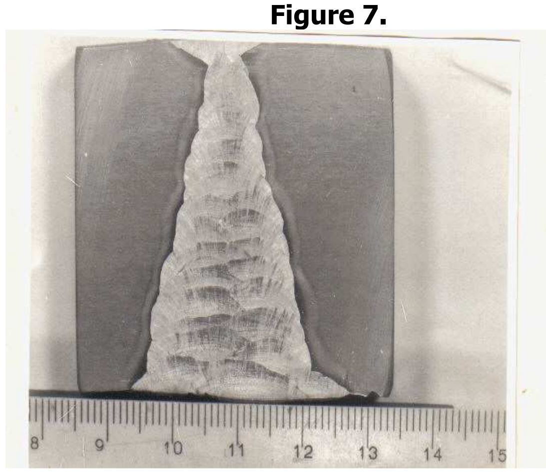

Figure 8.

The bending angles at d=30 are small 30^{O}C. The mechanical sample microstructure is shown in fig. 8 and the microstructures are shown in fig. 9 and 10.

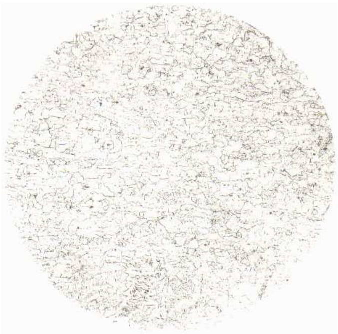

Figure 9. Microstructure – Z .I .T . : 100 x. **Figure 10.** Microstructure - M.B. :100 x.

4. Conclusions

Although the hardness in the transition area have high values, the resiliency is noticed to be higher than 3.5kgfm/cm2. Due to the fact that this part will be embedded in concrete when mounted in the station, it insufficiently stiff and it is not subject of bending during exploitation

As a conclusion, following the obtained results, the pre-heating temperature of 250^{O}C is considered sufficient for manual electric welding with covered electrodes, and the electrodes 25Cr20mNi are proper.

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