Some Problems of the Weldability of High Strength Thick Plate Steels Subjected to Electron Beam Welding†

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Abstract

Electron beam welding finds steadily increasing application in the joining of heavy thick plates. However, the high heat input of this welding source causes in some types of steels significant decrease of the mechanical properties, especially in the impact test value. This report tries to explain the reasons of this phenomenon.

KEY WORDS: (Electron Beam Welding) (Centrifuges) (Dynamic Fracture Tests) (Crack Propagation) (Vertical E.B. Welding) (Weldability) (Defects) (Hardness) (Thick Plate E.B. Welding)

1. Introduction

Electron beam welding steadily finds a wider field of application in the joining of thick materials[(1)]. However, any application should be deferred until full analyses of all aspects of welding and materials have been carried out.

The results presented below, of welding of 50mm thick and 500mm diameter tubes made from centrifugally casted SCW50-CF steel subjected to EBW, show the limited possibility of the application of this method. The impact test requirement of Japanese Industrial Standards (JIS) for this type of welded joint is 2.8kgf·m at 0°C at any place of the joint. This requirement is necessary because of the use of these tubes as welded pillars in the construction of elevated highways, especially in places of frequent earthquakes.

The limited investigation of welded joint has shown clearly that the application of highly modern and high density heat sourse electron beam welding should not be accepted for the welding of some types of materials.

2. Selection of Welding Conditions

This part of research follows previous work carried out on thick plates of SCW50-CF centrifugally casted steel which is very similar to HT50 in chemical composition.

The continuing of this research finds its ground in the previous results of very low impact test values of both deposited metal and bonding line of the welds. The results were below 2.8kgf·m at 0°C, the JIS requirement for this type of welded steel.

The welding conditions were almost the same, as in the previous carried out experiment.

They were:

Accelerating voltage – 100kV
Beam current – 240mA
Welding position – Vertical upward welding
Welding speed – 20cm/min
Wire feeding speed – 15m/min
Frequency of beam oscillation – 30Hz
Amplitude of oscillation
only on the specimen surface – 3mm
a_b value – about 0.9
($a_b = D_o/D_f$, where D_o is the object distance, and D_F is focal length).

These welding conditions were used because of the good penetration and no defects obtained under the previous conditions.

The same material as in previous work was used for this research, the chemical composition of which is shown below in **Table 1**.

Having proper welding coditions and the same materials, we have found that the most important factor improving the impact value is the elevation of preheating temperature. The temperature of 260°C was selected because it is intermediate between the previously applied 100°C and the martensite transformation temperature for this steel, about 400°C.

Although the preheating temperatures seem to be very high for practical application, we have decided to

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Table 1 Chemical composition of materials used (%)

Materrials		C	Si	Mn	P	S	O* (ppm)	N (ppm)	Ceq
Base metal	used	0.21	0.53	0.95	0.016	0.016		120	0.37
	JIS (max.)	0.20	—	—	0.04	0.04	—	—	0.44
Filler wire		0.10	0.54	1.07	0.015	0.009	60	43	—

apply them having in view the possibility of investigating the effect of the temperature on the joining of very thick plates using electron beam welding.

3. Preparation and Results of the Impact Test Specimen.

After welding on the work pieces the exact points for cutting of the notch were marked using macro-etching methods. Then, the specimens were machined and tested at 0°C temperature.

Although the impact values of the deposited metal and heat-affected zone were generally positive, the impact test values of the bonding line were very often negative, which means that the elevation in preheating temperature did not cause any visible improvement. The most interesting results were in the case where two very closely neighbouring speciments cut out from the bonding line showed one positive and the second one negative results **(Table 2).**

Table 2 Absorbed energy at 0°C (kgf·m)

Mark		Deposited metal	Bonding line	HAZ
P168	B1	5.7	5.7	7.9
	B2	5.9	1.6	12.5

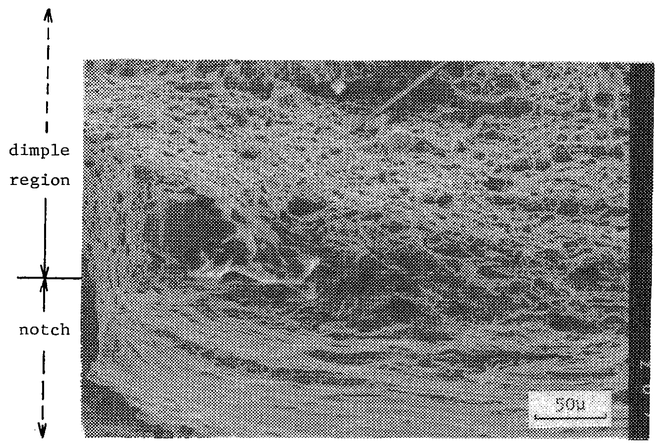

Fig. 1 Wide dimple region at the vicinity of the bottom of the notch in the positive specimen (B1)

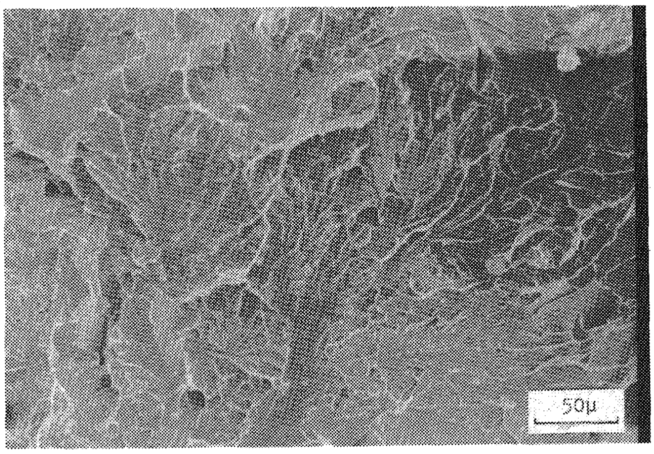

Fig. 2 Example of unit crack path at the cleavage fracture surface in the positive specimen (B1)

4. Research Work and Results

The above mentioned two specimens were subjected to the following investigations or tests:

a) Micro – fractography
b) Macro – and Micro – Structure Analyses
c) Hardness Tests

a) Micro – fractography

The structures of the fracture surface of the positive specimen are shown in **Fig. 1 and 2**, and of the negative one in **Fig. 3** and **4**. In Fig. 1 is very clearly visible a wide dimple region and in Fig. 2 and 4 are shown relatively big unit crack paths going along the full surface. However, the path in Fig. 4 is generally somewhat larger than in Fig. 2. In Fig. 3, the dimple region is very narrow.

Because the sizes of the unit crack paths are almost equal, it means that the fracture is going through very similar regions of the structure. This region could be identified as the bonding line.

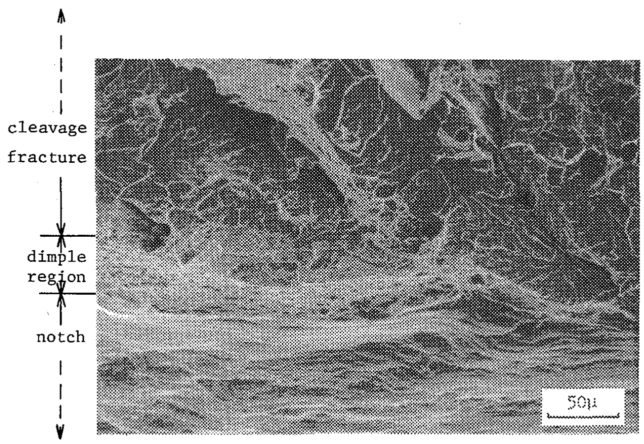

Fig. 3 Very narrow dimple region at the vicinity of the bottom of the notch in the negative specimen (B2)

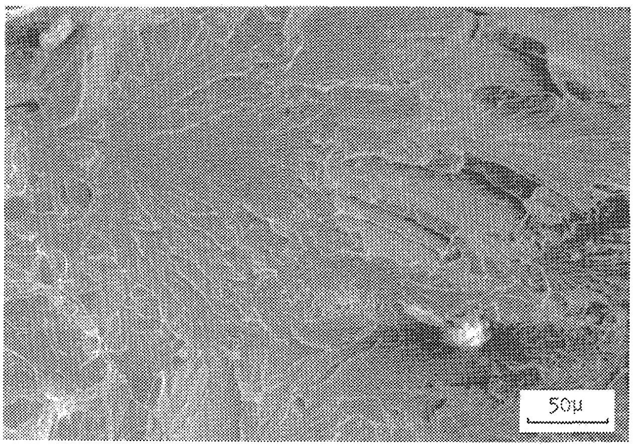

Fig. 4 Example of unit crack path at the cleavage fracture surface in the negative specimen (B2)

The observation of the large unit crack path in both specimens suggests the possibility of low ductility connected with the microstructure.

The analyses of Fig. 1 and 2 show that the wide dimple region does not relate to a small unit crack path. It means that the propagation of the fracture going out from the high ductility region went after that to the brittle path of the weld structure, which means that the beginning of the fracture started in the ductile deposited metal and then went to the brittle bonding line and went straight along it to the end. Confirmation of this explanation is very exactly seen in **Fig. 5** and **6**, where in Fig. 5 the crack is very much more developed compared with the very straight line of the fracture in Fig. 6.

b) Macro-and Micro-Structures

The Fig. 5 and 6 show the kind of fractures in the B1 and B2 specimens as well as size and measures of the related zones of the welded joints. The very first observation of both the macrostructures shows highly developed prior austenite grain size in the bonding line.

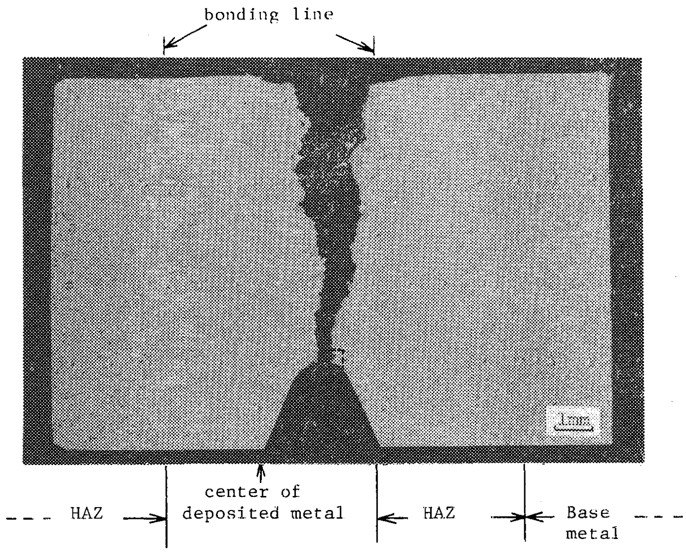

Fig. 5 Macroscopic view of fracture path in the positive specimen (B1), showing developed fracture line partially following the deposited metal.

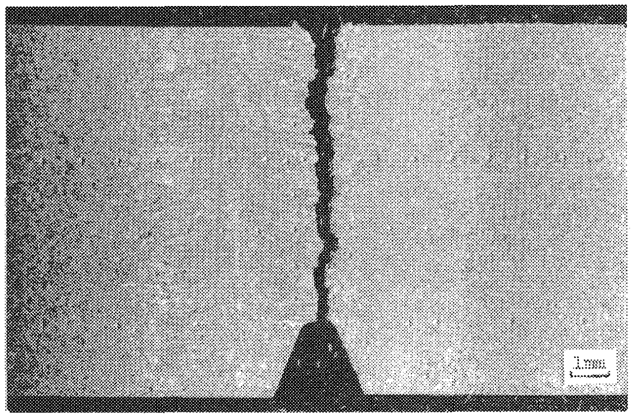

Fig. 6 Macroscopic view of fracture path in the negative specimen (B2), showing almost straight fracture line going exclusively through the bonding line.

The more exact pictures of the starting of fractures are shown in **Fig. 7** and **8**. Related to Fig. 7, is the microstructure shown in **Fig. 9**. The arrow shows very deformed structure on the bottom of the notch, where the fracture started. **Figure 10** doesn't show any deformation on the edge of fracture, which means that the fracture went exactly through the brittle region of the bonding line. This figure shows the typical structure of the deposited metal.

Figure 11 shows the deposited metal in the middle of the weld joint and **Fig. 12** shows the structure of the base metal.

c) Hardness Tests

The hardness tests of the two specimens show any specific differences, although the hardness changes continuously from base metal over heat-affected zone and reaches its maximum hardness in the bonding lines. The fracture in both cases went through the

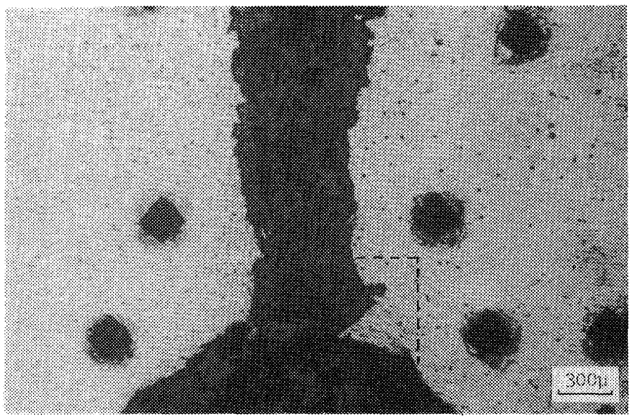

Fig. 7 Detail of the bottom of the notch showing the initiation of the fracture in the deposited metal in the positive specimen (B1)

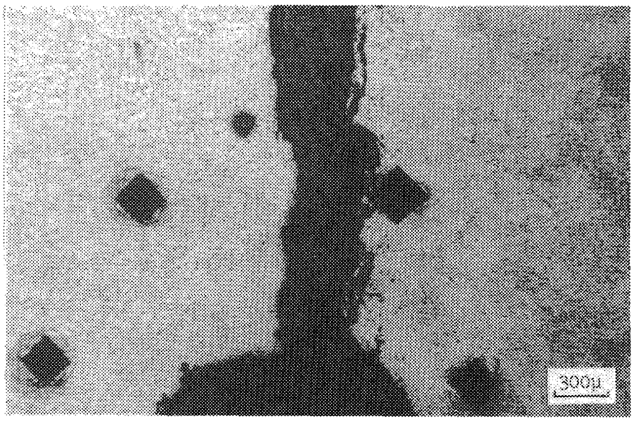

Fig. 8 Detail of the bottom of the notch showing the initiation of the fracture in the bonding line in the negative specimen (B2).

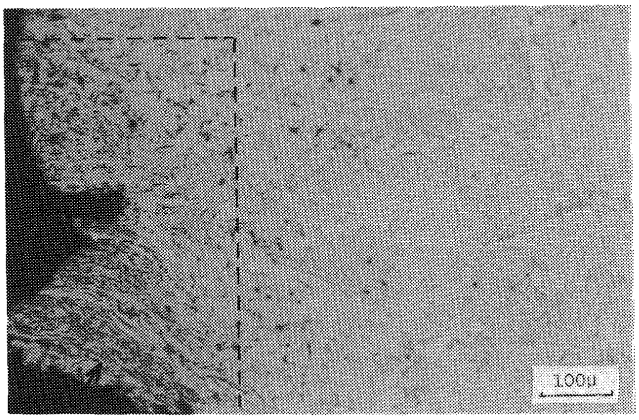

Fig. 9 Microstructure (specimen B1) in the vicinity of the initiation crack region. The arrow shows in high magnification the deformed deposited metal where the crack started.
The figure generally shows the structure of the bonding line which is large proeutectoid ferrite, ferrite side plate and upper bainite.

(The microstructure proves the assumption that initial austenite grain size was large and the cooling rate was relatively low.)

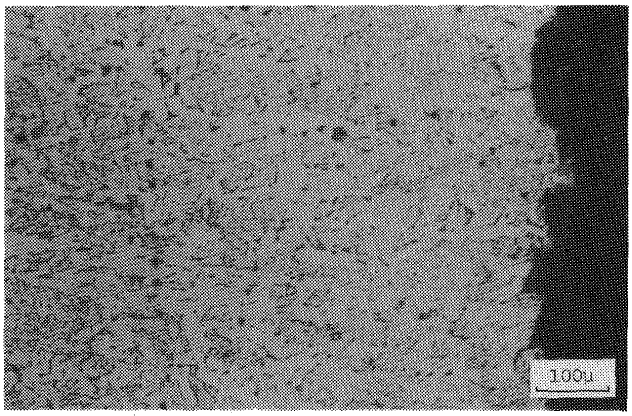

Fig. 10 Microstructure of the deposited metal in the negative specimen (B2). There is no deformation on the fracture edge, and the microstructure consists of relatively fine ferrite and pearlite and partly of bainite.

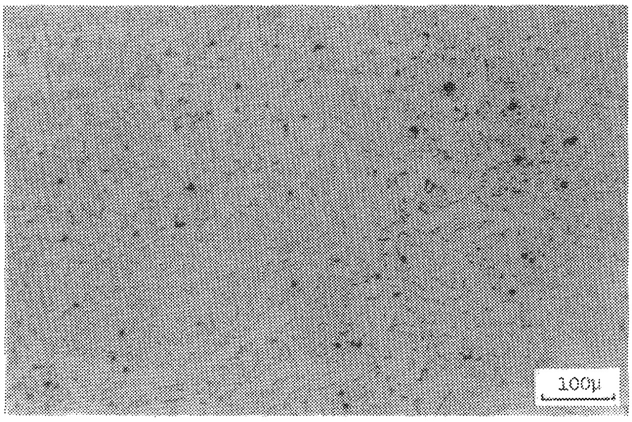

Fig. 11 Microstructure in the center of the deposited metal shows relatively fine ferrite and pearlite and some bainite. There are some inclusions which probably were connected with higher oxygen content in filler wire and influenced positively the fine structure.

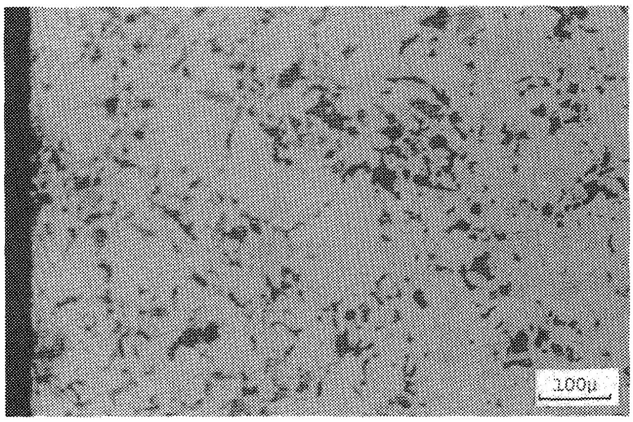

Fig. 12 Typical microstructure of base metal showing ferrite and pearlite.

strip where the hardness is highest. These were our findings, but we could not find a proper explanation for why the hardness changes from its minimum at the bottom of the notch and reaches its maximum on the top of the specimen.

Because of very similar hardness values in both specimens, the hardness could not give any valuable hints for the different absorbed energy during the impact tests. So must try to find the explanation of the phenomenon in the changes of the structure of metal submitted to the specific thermal cycles of the electron beam welding.

5. Summary and Discussion of Results.

Deeper anylysis of the above shown results lets us come to the conclusion that the impact test value of the "positive specimen" was a result of improper cutting of the notch in this specimen. As **Fig. 13** (b) shows the crack initiated outside of the bonding line and then partially followed this line giving as a result a relatively high impact value and it is necessary to say that this result could not be acknowledged as a proper one. On the contrary, the "negative specimen" (Fig. 13c) shows the very straight way of the fracture going thoroughly through the strip of the bonding line. This result which is 1.6kgf·m we must acknowledge as a proper one. If so, we should find explanation why so very low ductility occurs after welding in the allegedly sufficiently high ductile researched material.

It is necessary to state that this same material submitted to CO_2 gas arc welding[2] shows sufficiently high results of the impact test specimens cut out from the bonding lines.

The microstructure analyses on the bonding line of Fig. 9 shows large proeutectoid ferrite, ferrite side plate and upper bainite. These structures occur during welding with high heat input by different methods of welding. Since in our case the welding conditions applied for the welding of the 50mm thick plate didn't give any negative result, it means that the shape of welds were correct, as well as no defects occured. So we must acknowledge that these welding conditions were properly chosen, but they caused the negative structure as shown in Fig. 9.

The occurence of this structure could take place-as was mentioned above-by high heat input, an external factor, as well as by the influence of inner factors, especially the chemical composition. The analysis of the chemical contens in researched material shows not

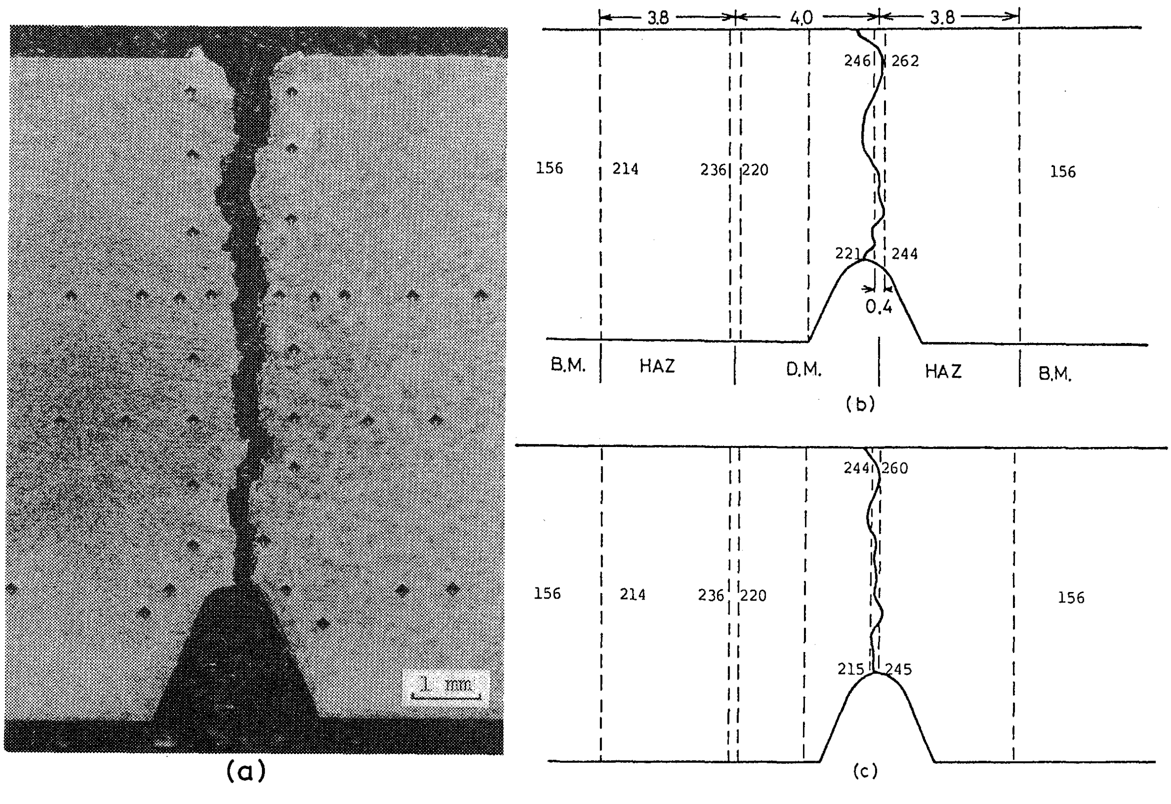

Fig. 13 Hardness distribution and sizes of weld zones in both specimens.
(a) The kind of measurement
(b) Hardness value in positive specimen (B1)
(c) Hardness value in negative specimen (B2)

only high carbon and manganese content, but also untypically high content of nitrogen.

According to recent research[3][4][5], the high heat input and high nitrogen content cause the occurrence of the Martensite-Austenite (M − A) constituents inside the upper bainite which decidedly and extremely lowers the impact values of materials.

Negative result of the impact test could be theoretically changed when using higher preheating temperature or PWHT. As we have mentioned in the beginning of this report, the applied preheating temperature 260°C is the intermidiate temperature between 100°C and Ms transformation temperature. Both the high preheating temperrature and PWHT are however almost impossible to apply from the practical point of view. In such a case there are only two possibilities of avoiding negative results of impact value in the bonding line. The first one is the complete change of the material used for the welded tubes in the pillars of eleveted highways, and the second one is the attempt to improve actually used material. In this case the main idea should concern the reduction of carbon and nitrogen content as well as alloying this material with B, Ti and perhaps REM.

6. Conclusions

1. The investigation of the insufficient value of the impact test according to requirement of JIS has shown that reason for this low value is the high carbon and nitrogen content and high heat input. Due to these factors it is highly possible that the M-A constituent is entirely resposible for the insufficient and low absorbed energy in the impact test.

2. The combination of EBW for welding of up to date SCW50-CF steel under industrial conditions of fabricating the pillars can not give any positive result.

3. If a positive result of the impact value is desired this research indicates two possibilities: to change or to modify the actually used material.

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