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Corrosion behaviour of the welded steel sheets used in automotive industry

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Properties

ABSTRACT

Purpose: of this paper is to characterise the corrosion resistance in the steel sheets (Hot dip galvanizing of steel sheets) used in automotive industry. In fact, corrosion of automotive components by road salt is a widely known problem. The different parts under the car body and the interior surface of body panels suffer easily from the corrosive products deposited on roads and used mainly to melt snow. A comparison in a chemical investigation of the corrosion rate for base metals (without welding) and welded steel is required. Therefore, conformity will be accomplished between the corrosion phenomena in simulated corrosion tests and those in actual cars.

Design/methodology/approach: Simulated corrosion tests, wet/humidity test and hot dust/dry cycle talk test carried on in laboratory conditions was investigated quantitatively. Dynamic behaviour of the corroded specimens have been tested dynamically to simulate under the crash test conditions.

Findings: Studies carried out on the vast corroded samples have shown that the pitting corrosion damage and crack initiation sites have began and propagated generally in the HAZ in the welded steel sheets (Tailored welded blanks - TWB).

Research limitations/implications: This paper contains partially results of a common research project. Some limitations exist in application of hot dust/dry cycle talk to the real open air test conditions. All of these results were carried out in the laboratory conditions.

Practical implications: The problem is of extreme importance to all academic, scientific, manufacturing, maintenance and industrial societies. The outcome of the proposed study will contribute to the industrial application of ARCELOR-MITTAL. The proposed study will be benefit not only for the car industry and steel makers, but also important for the other industrial applications. The proposed research can be employed in a broad range of applications in oil and natural gas industries. This project will promote multidisciplinary research and cooperation between university and industry.

Originality/value: An effective corrosion test proposed by Volvo was applied to the welded sheets (TWB) in an enclosed climatic chamber. This test is a practical and inexpensive test. Impact tensile-crash test makes it possible to analyse the corrosion damage of sheet metals under the dynamic rupture.

Keywords: Corrosion; Welded Tailored Blanks (TWB); Automotive industry; Impact tests; Damage mechanism

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1. Introduction

The enormous usage of thin steel sheets for automotive application for reducing car weight necessitates improved material strength in addition to higher corrosion protection. Hot dip galvanizing of steel sheets has become known as a powerful protection technique towards oxidation and hence, failures due to corrosion. For the automotive industry, these thin steel sheets are often galvanized or galvannealed (GA). The galvannealed coating consists of several zinc–iron intermetallic phases, the nature and thickness which influences the mechanical properties, especially the powdering resistance of the material [1]. The present tendency comprises various post-galvannealing treatments to progress corrosion resistance, such as paint appliances. This reduces to a large extent the under-film corrosion deep-scratch [2]. Considerable improvement in the hot dip galvanizing, particularly in the areas of consistent thin coating as well as removal of surface defects, has involved large scale replacement of electro galvanized (EG) products by hot dip galvanized material. The highest quality standards are presently being demanded by the car industries.

Among the various coated products, galvannealed steel sheets are now being extensively used by the auto makers because they display excellent corrosion resistance after paint application. In fact, the surface appearance of galvannealed steel is grey, matted, uniform and without sparkle because it is reheated (500–550 °C) just before solidifying that gives an excellent paint adherence and corrosion resistance after painting. It also shows relatively good weldability (mainly high quality in resistance spot welding). For that reason, GA coating, in arrangement with paint, provides additional effect against corrosion and consequently, is used for aesthetically demanding applications such as automobile exposed body panels [3, 4].

In several decades, the development of interstitial free (IFS) steel satisfies the strict demand of automobile manufactures due to their excellent formability [2]. IFS are produced by adding titanium and/or niobium and/or boron to an extra low carbon grade to precipitate interstitial carbon and nitrogen atoms [5-8]. The demands for good protection against corrosion in a wide variety of finished products have resulted in the increasing use of galvanized steels. Galvanizing is the process of forming a zinc layer that is metallurgically bonded to the iron or steel's surface. Besides corrosion protection, zinc coating is applied to sheets for others reasons, including soldering capacity, temperature resistance, lubrication and paintability, etc. The hot dip galvanizing is the most extensively used galvanizing process, which involves immersing very clean steel sheet, as a continuous ribbon, into a zinc molten bath at the temperature 450–460 °C.

Automotive corrosion is classified into three types, perforation corrosion, cosmetic corrosion, and edge corrosion. Perforation corrosion is the most important problem rather than cosmetic corrosion and edge corrosion. Corrosion-resistance quality targets for the car have been established in North America and northern Europe to reduce automotive corrosion, including the Canada Code I (1978), Canada Code II (1981), Nordic Code (1983), and the intended targets of US-Biggest-3 (GM, Ford, Chrysler; 1989). Subsequently, requirements for corrosion resistance have become progressively higher, as it is seen in the intended 12-year corrosion guarantee proposed by the major European car makers in 1998. Since the 1990s, studies of the actual condition of automotive corrosion in areas, where de-icing/de-snowing salt was used, have been carried out in Europe, North America, and Japan [1-9]. The results composed many corrosion studies on a large number of auto parts from cars used in northern Europe revealed that the main factor affecting perforation corrosion in automobiles was not the type of coating, but the coating weight.

Today, new tendency in the European automotive industry is the vast use of hot dip galvanized steel sheets. Exposed panels, floor pan, air cleaner tray, oil sumps, fenders, quarter panel, rear compartment pan, front floor pan, etc. are typical applications of hot-dip galvanized steel sheets (Figure 1). Thus, formability of hot dip galvanized steel sheets has been one of the key topics in the automotive industry's evolution to higher corrosion resistance of car parts. The main objective of the present paper is to carry out comparative study on the corrosion behaviour of the thin sheet steels (base metal and welded metal-Tailored welded blanks, TWBs) used by European car industry.

On the other hand, it is well known that amongst the material properties, corrosion is one of the most challenging and important properties, especially for oil and gas industry applications where every year corrosion costs billions of dollars to oil and gas companies [10]. Every component in oil and gas industry is attacked by corrosion and special attention must be given to down-hole applications where combined effects of temperature, stress and corrosive environment are present. Moreover, the Arabian Gulf region has very severe conditions where the average maximum temperature is 33°C (in summer it reaches 50°C), the relative humidity is 76%, the average salinity is ~5 $\mu g\ m^{-3}$, the maximum chloride and sulphate levels in the air are 9 and 50 $\mu g\ m^{-3}$, respectively [11]. There are so many factors and elements responsible for corrosion but the most important ones to consider are; oxygen, formation fluids, drilling mud, water and carbon dioxide, high velocity sand, hydrogen sulphide and complications from temperature, pressure and stress. There are several corrosion mechanisms that should be considered when designing a part in oil & gas industry such as; galvanic, crevice, pitting, stray-current, chemical, biological (generation of H_2S by bacteria), cavitation and erosion corrosion.

Additionally, failure might occur due to corrosion fatigue, stress corrosion cracking, hydrogen embrittlement, sulphide and chloride stress cracking [10, 11]. The presence of this hot and highly corrosive environment suggests that the corrosion properties of each part used in oil & gas industry must be studied thoroughly. Particularly, the material behaviour in chloride and sulphate rich atmospheres must be investigated in details for safety and optimum performance.

It is clear that operation environment, temperature and material composition substantially affects the corrosion properties of steel alloys. Additionally operating under stress can also affect the corrosion properties. Indeed, stress corrosion cracking is one of the main problems in the parts used in oil industry. All these parameters should be considered in a methodically investigation of the corrosion properties of these alloys by simulating their application environments. For this reason, this investigation is among the focused research areas of priority to desert regions (for the Arabian Gulf region) in “materials”, specifically “corrosion”. It produces valuable results regarding to the different grades of steels.

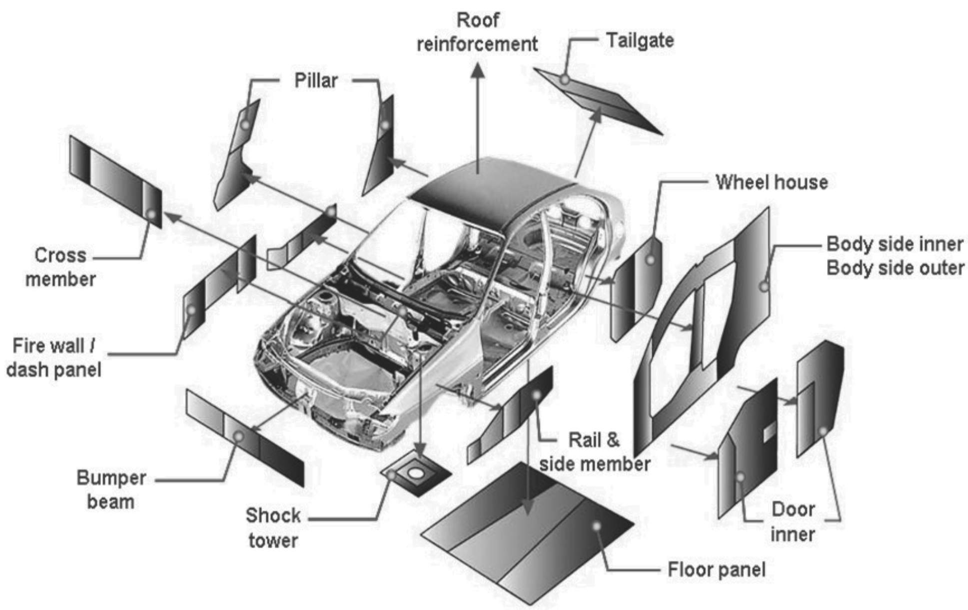

Fig. 1. General application of thin sheet steel as Tailored Welded Blanks (TWBs) in car industry [9]

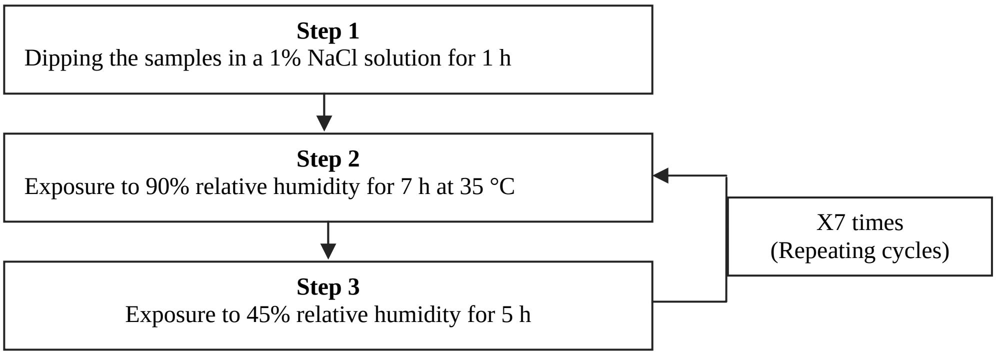

Fig. 2. Experimental procedure of (VOLVO) corrosion test

The proposed work will open new research directions in engineering and can serve many interests in advanced research and education in materials science and manufacturing engineering.

2. Experimental discussion

2.1. Identifying the corrosion tests

Wet/Humidity test

The Volvo indoor corrosion test was performed according to the standard STD 1027, 1375. The test specimens are placed in an enclosed chamber and exposed to a changing climate that comprise of 3 different climate conditions. Firstly, the samples are dipped in a 1 % NaCl solution in order to simulate a road environment, where sodium chloride (NaCl-salt) is the dominant corrosive element. Then, the samples are exposed to 90 % relative humidity for 7 hours at 35 °C followed by an exposure to 45 % relative humidity for 5 hours. The second and third steps are repeated for 7 times giving a total exposure time of 84 hours (3.5 days). The Figure 2 represents schematically this experimental procedure of corrosion test.

Hot dust/dry cycle test

This type of test is generally carried out according to IPx5-CEI 60-529, in compliance with ISO/CEI/17025 standard and COFRAC rules. The Dust Test Chamber is specially designed to simulate a dust filled atmosphere in a confined workspace as international testing standards especially in automotive and electronic components testing of its resistance to dust atmosphere. For this test, it can be created a desert storm or the air blast from an aircraft with the wind-driven abrasion and erosion of sand and dust, can be recreated, combined with actual temperatures. “Mil-Std” environmental testing is performed in our facility with collaboration with a research laboratory (L2EC) that is located in

Paris. Laboratory conditions have been arranged according to the real test conditions for the performance and simulating real open air test conditions.

For accomplishing simulated tests applications, combined effects of temperature, stress and corrosive environments have been presented. In fact, this type of test has been arranged essentially for the Arabian Gulf region in severe conditions where the average maximum temperature is 33°C especially when the temperature reaches 50°C in summer. These laboratory tests are partially results and the general test conditions will be carried out later in the frame of the research project that is going on.

2.2. Set up used in laboratory for the Volvo corrosion test

The samples were exposed to changing climates created by a humidifier placed in this oven. The temperature and the relative humidity were continuously measured by a hygrometer of which the probe is also placed in the enclosed chamber. Some of the specimens containing resistance spot welding and LASER welding were kept under the constant stress during the test.

Figure 3 display the whole laboratory set up of corrosion (oven + specimen setting + hygrometer, etc.) and also Impact tensile-crash test specimens before and after the corrosion exposing cycle.

2.3. Welding processes and impact tensile-crash test conditions

Different IFS-Interstitial Free Steel grades (Hot dip galvanizing of steel sheets) were used in this study used principally in car industry. The carbon and manganese contents vary from 1.4×10^{-3} to 5×10^{-3} wt% and from 200×10^{-3} to 1440×10^{-3} wt%, respectively. Thickness of steels varies from 0.7 to 2mm. LASER-Welding power energy varied from 0.9 to 5.5 kW with the welding speeds going from 2, 2.5 to 3 m/min. The morphology of the welded zone made it possible to evaluate the values of the thermal yielding-efficiency of LASER welding process going from 9% to 13%. Structural examination allowed to estimate the speed of solidification about $10^5 - 10^6$ (C/s).

Resistance spot welding was performed using a 30kVA, pedestal SBF44 type machine and welding parameters are chosen in conformity with the IIW and also NF A87-001. Electrode: truncated cone, 6 mm^{Ø}, electrode force: 210 daN, weld time: 7 and 16 cycles, hold time: 7 and 50 cycles and welding current: adjusted (5.5 and 8.8 kA) for obtaining different nugget diameter.

The temperature of ductile-brittle transition from the base metal and LASER molten metal and or resistance point, welding was measured by impact tensile test (ITT) [12-16]. All of the tests have been carried out under the same conditions on the specimens before and after the corrosion test.

3. Results and discussion

3.1. Microstructural evaluation of the specimen exposed to the corrosion test

Microstructure evaluation has been carried out on the specimens regularly after the corrosion test. General idea was that is to observe the damage in microstructure and naturally to determine the type of the corrosion. Figure 4 shows the macrographs of IFS steel samples before and after corrosion test. The corroded site and whole degradation of the sample surfaces are well observed that the corrosion damage concentrated around the welding line.

In the Figure 5, the microstructure of the IF-NbB steel grade (LASER welded) was shown as an example. General damage was due to the pitting corrosion. Here the HAZ and Weld bead have undergone heavily damage after exposing the corrosion.

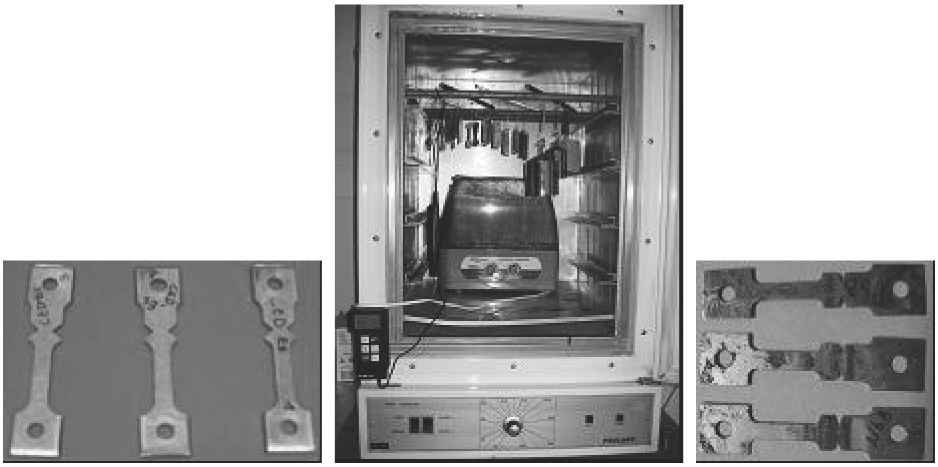

Fig. 3. Laboratory set up of corrosion (oven + specimen setting + hygrometer, etc.); Impact tensile-crash test specimens before and after the corrosion exposing cycle

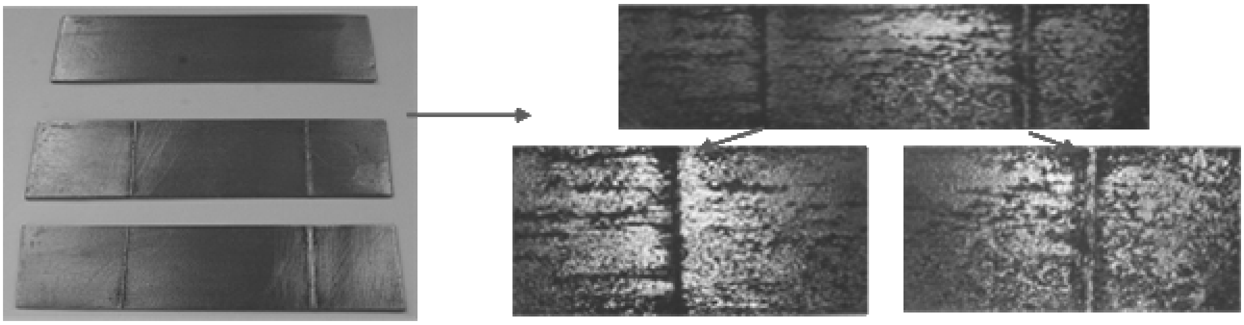

Fig. 4. IFS steel samples before and after the corrosion test

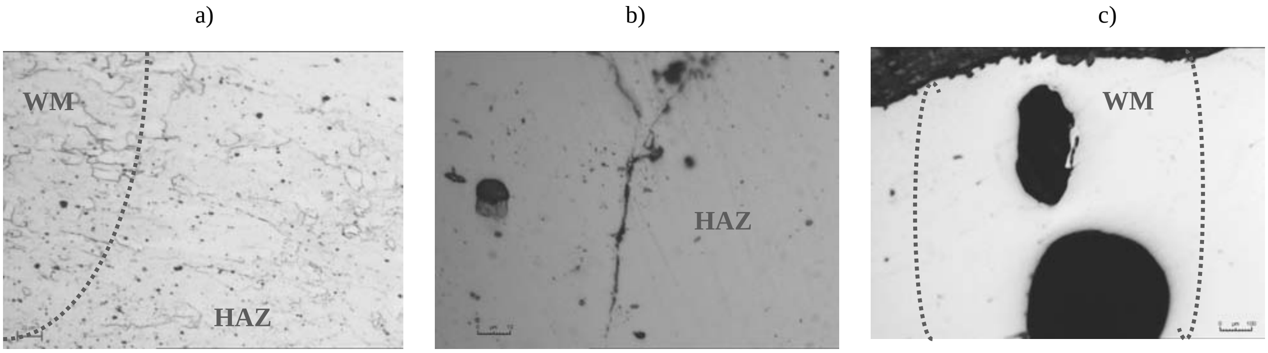

Fig. 5. Microstructure of the IF-NbB steel grade (LASER, weld bead and HAZ)

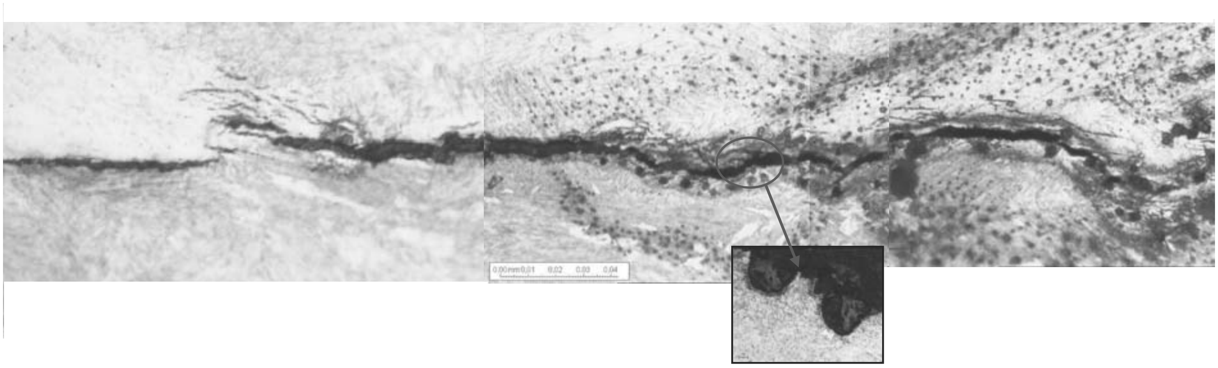

Fig. 6. Damage in the HAZ of the IF-NbB steel grade kept under the stress during the corrosion (RSW)

The other IFS grades have shown similar damage and corrosion generally has been concentrated in the HAZ. Crack initiation site and propagation after the pitting sites inside the specimen was observed in the specimen that was kept under the stress during the corrosion test (Figure 5b). A typical porosity in the corroded specimen (in the weld bead of IF-NbB) was shown in the Figure 5c. However, observations carried out on the vast corroded samples have shown that the pitting damage and crack initiation sites were generally in the HAZ. Naturally, HAZ zone of these grades show mainly metallurgical problem like grain growth in HAZ [13] even if some of the grades such as IF-TiB show a HAZ containing less defects regarding the other IFS grades.

Figure 6 expose a typical example of pitting damage in the microstructure of IF-NbB grade containing Resistance Spot Welding (RSW). Here, the specimen was kept under stress during the corrosion; Crack initiates just near the nugget (RSW) and propagated through the HAZ. After the entire corrosion test, the corroded specimens containing LASER welding line and RSW have been compared for general evaluation. All specimens containing RSW have shown regular pitting damage and crack propagation which was much higher than the other samples containing LASER welding.

3.2. Impact Tensile-Crash tests (ITT) of the specimen exposed to the corrosion test

The main principles of the impact – crash tests (ITT) has been explained formerly in literature and recently applied with success for testing the welded thick and thin plates. In accordance with this type of the test principle, the specimens are submitted to impact tensile testing at different temperatures. In fact, the ductile-brittle transition temperature (DBTT) depends naturally on various parameters such as temperature, specimen thickness, deformation rate, notch geometry, metallurgical factors etc. Evaluation of ductile-brittle transition temperatures of welded sheets exposed to the corrosion test is a sensitive parameter and is a very useful tool to qualify new welding processes especially to study their corrosion behaviour. On the contrary to base metal testing, specimens including welds have heterogeneous structure because of local modification during welding. Fracture competition between these two sections during impact loading is more complex because of different mechanical properties [10-12].

In this study, the ITT tests were carried out on the IF & BH steel grades; LASER welded IFS (IF-Ti, TiNb, NbB) and BH specimens including a smooth part and a notched (welded) part and also RSW. Specimens with a special device have been mounted on an impact pendulum [12]. According to testing conditions and material toughness, fracture occurs in one of these two zones with a very sharp transition.

The Figures 7a, 7b and 7c show the evolution of the DBTT of the IFS specimens prepared from TWBs. All of the Impact Tensile Tests have been carried out before and after wet/humidity corrosion test under the same conditions. These diagrams gave us a confidence evaluation of DBTTs for the same grades to compare their corrosion behaviour. For the grade of IF-TiNb, DBTTs of the specimens before and after corrosion are found to be around -135 and -120°C, respectively (Figure 7a).

Again, for the grade of IF-NbB, DBTTs of the specimens before and after corrosion are found to be around -125 and -75°C, respectively (Figure 7b). The test carried out on the grade of IF-TiB, the DBTT results are found to be around -125 and -90°C, respectively (Figure 7c).

However, the specimens containing Resistance Spot Welding (RSW) have shown very poor results (not shown here). All of the specimens display very low rigidity and they have given always brittle fracture and never ductile fracture after the corrosion test. General crack initiation site was found around the Heat Affected Zone (HAZ). The resistance of the specimens containing RSW is much lower than the LASER welded specimens.

These results are well-founded for all of the steel grades presented in this paper. In summary, corrosion cracking and/or damage in the welded specimen containing RSW begins always much well before than the specimens containing LASER welding process.

As for Hot/Dust corrosion test carried out in the simulated test conditions in laboratory scale has given very bad results comparing to the wet/humidity tests. Ductile-Brittle Transition Temperature (DBTT) of IFS-steel grades before and after hot/dust corrosion tests are shown in the Figures 8a, 8b and 8c. All of Impact Tensile Tests have been carried out before and after hot/dust corrosion test under the same conditions.

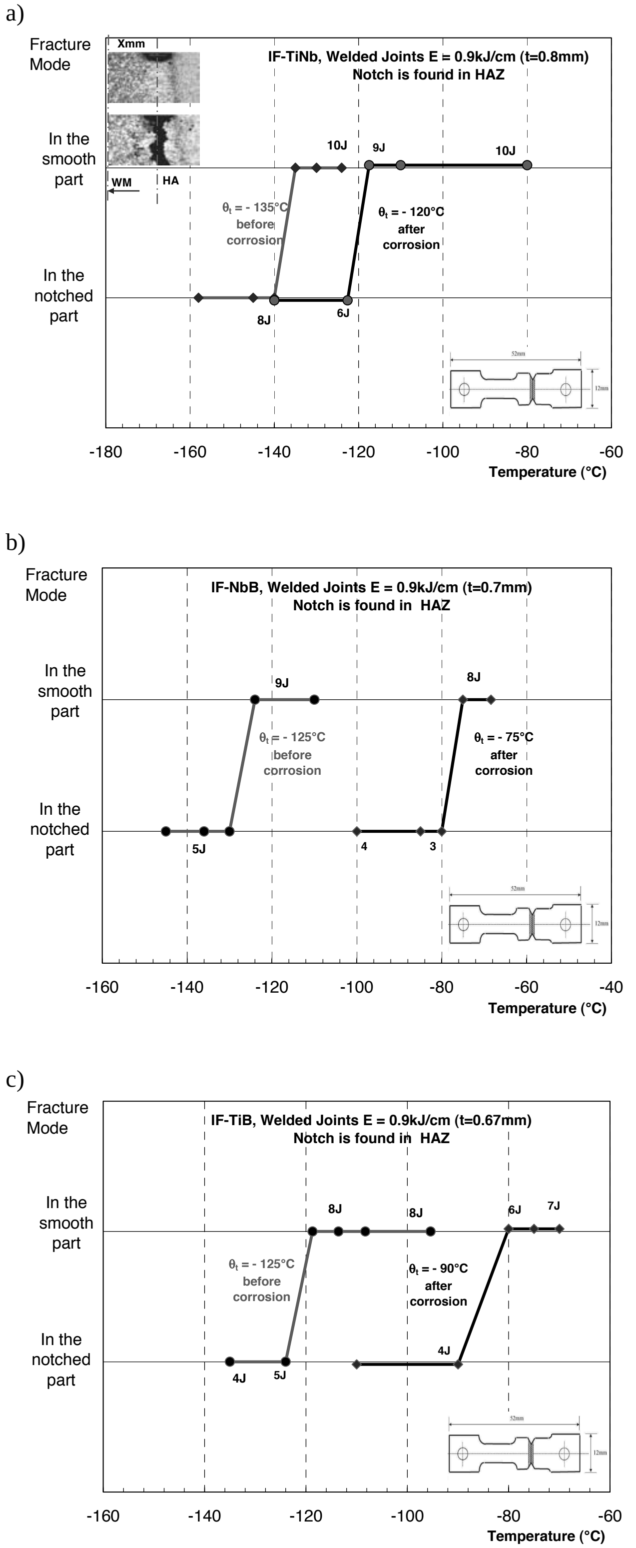

Fig. 7. Ductile-Brittle Transition Temperature (DBTT) of IFS-steel grades before and after wet/humidity corrosion

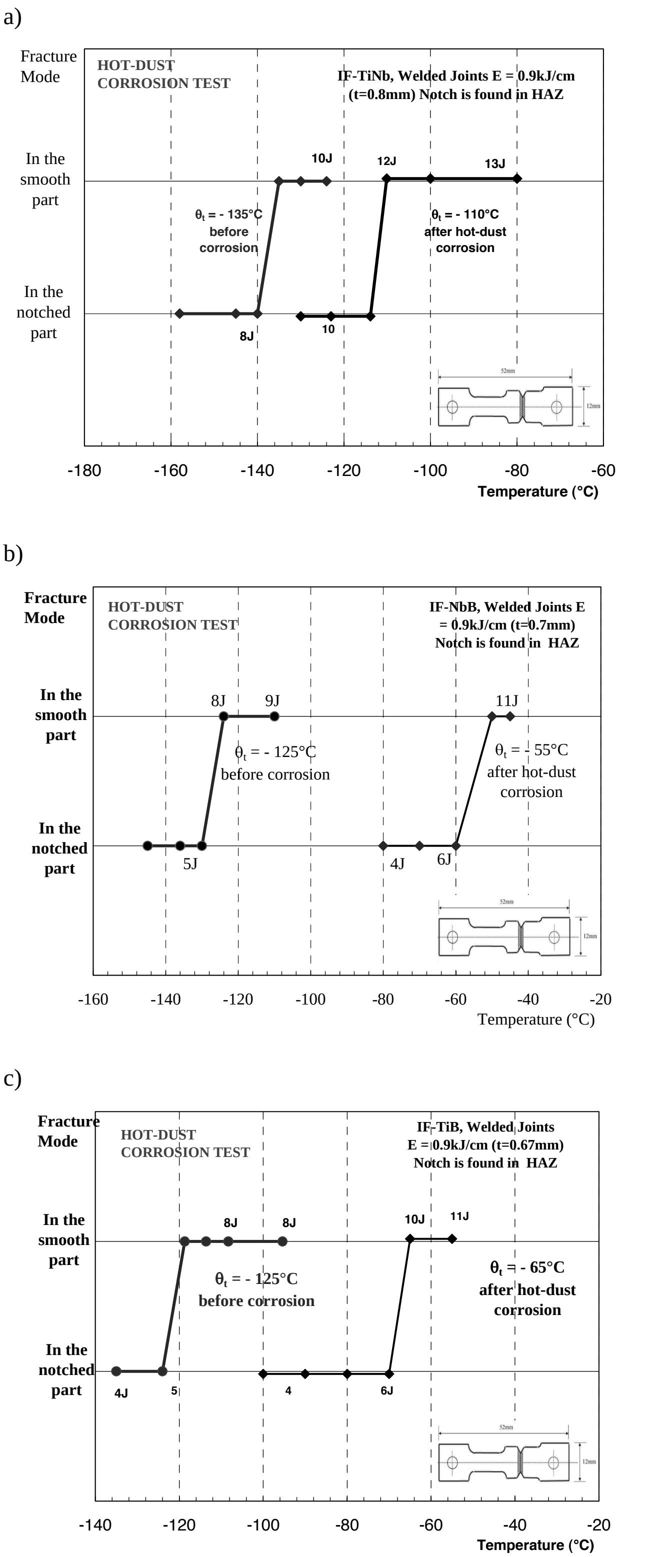

Fig. 8. Ductile-Brittle Transition Temperature (DBTT) of IFS-steel grades before and after hot/dust corrosion

As indicated just above, these laboratory tests are partial results and the general tests in real open air conditions will be carried out later in the frame of the research project that is going on. At the first stage, the impact tensile (crash) test behaviour of these steel sheets have been compared for two types of the corrosion tests (wet/humidity and hot-dust) in Table 1. For all of the steel grades, hot – dust corrosion test results have been found lower than those of wet/humidity tests. Essentially, the grades of IF-NbB and IF-TiB have shown very brittle behaviours in the case of hot-dust test conditions. These tests have given important hints for the composition and separate behaviour of the alloying elements. Here, an attention is drawn to a special role of Boron during the corrosion process in hot dusty conditions. His behaviour in severe test conditions as indicated in former papers is segregation in the grain boundaries [15, 17].

Table 1.
Comparison of Impact crash behaviour of IFS-steel grades before and after two types of corrosion tests

Steel grades (Welded Joints)	Before corrosion	After wet/humidity corrosion	After Hot-Dust corrosion
IF-TiNb	-135°C	-120°C	-110°C
IF-NbB	-125°C	-75°C	-55°C
IF-TiB	-125°C	-90°C	-65°C

More details for metallurgical reasons for this very brittle behaviour of some of the steel grades will be given after this test series completion.

4. Conclusions

A comparative study on the corrosion test has been given for the thin sheet steels (Interstitial Free Steels) used in automotive industry.

Effective corrosion tests, wet/humidity test proposed by Volvo and hot-dusty test were applied to the welded steel sheets (Tailored Welded Blanks) in an enclosed climatic chamber according to the test standards. These tests are practical and inexpensive tests in practical applications.

Impact tensile-crash test makes it possible to analyse the corrosion damage of sheet metals under the dynamic rupture.

Observations carried out on the vast corroded samples have shown that the pitting corrosion damage and crack initiation sites have began and propagated generally in the HAZ.

After the completed corrosion tests, all of the corroded specimens containing LASER welding line and RSW have been compared for general evaluation. All specimens containing RSW have shown regular pitting damage and crack propagation was much higher than the other samples containing LASER welding.

For all of the steel grades, hot – dust corrosion test results have been found lower than those of wet/humidity tests.

More details for metallurgical reasons for this very brittle behaviour of some of the steel grades will be given after this test series completion.

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