EXTENSIVE INTRODUCTION OF ULTRA HIGH STRENGTH STEELS SETS NEW STANDARDS FOR WELDING IN THE BODY SHOP

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ABSTRACT

In order to meet upcoming legislative demands regarding acceptable levels of CO_2 emissions and to contribute to the fight against global warming, while also meeting customer expectations of reduced fuel consumption, all automotive OEMs are today focusing on lightweight engineering. Some of them, mainly low volume premium brands, have chosen to introduce fairly expensive lightweight materials such as aluminium and magnesium to meet these targets, whereas the main portion of high volume producers are trying to optimize the classic steel concept by introducing different grades of advanced high strength steels. Volvo Cars has decided upon a unique utilization of hot-formed, press-hardened, ultra high strength steel components featuring tensile strength levels in the order of 1 500 MPa, but on the other hand, producing these parts in very thin gauges for weight saving reasons. The first product launched according to this ultra high strength steel intensive concept was the 2008YM version of the Volvo V70 and its sibling, the cross-country version XC70, both built on the EuCD platform. The body contains several parts manufactured by hot-forming and press-hardening. The extensive use of this type of Boron alloyed steel challenged all welding methods commonly used in car body manufacturing, not least, traditional resistance spot welding. This paper will address the following topics: overview of the V70 body structure and utilization of materials, a brief description of the hot-forming, press-hardening process, the procedure for validating weldability before going into series production, lessons learnt from resistance spot welding trials of material combinations involving one or more boron alloyed steel parts, and recommendations for default welding data, influence on the manufacturing system, introducing electro-servo welding guns, adaptive weld timers and ultrasonic non-destructive weld quality checking, necessary revisions of existing spot weld requirements. The presentation will end with a glimpse at perspectives for future welding challenges in Volvo body shops, as the need for further weight saving will promote a considerable introduction of various new grades of advanced high strength steels.

IIW-Thesaurus keywords: *Automobile engineering; Hardening; Heat treatment; High strength steels; Manufacturing; Nondestructive testing; Process conditions; Process parameters; Quality; Resistance spot welding; Resistance welding; Steels; Ultrasonic testing; Welding.*

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1 INTRODUCTION

Volvo Car Corporation (VCC) has a long tradition of manufacturing premium automotive estate models, something that dates back to 1953 and the introduction of the classic “Duett” model – a revolutionary concept at that time. Since then, numerous 5-door body styles have passed through the body shops in the two volume plants, Torslanda (Gothenburg, SWE) and Gent (BEL), continuously upgrading typical Volvo features such as crash safety, endurance and quality. With the added values of distinguished design features and environmental concern, Volvo's latest estate models, the V70 and its cross-country sibling the XC70, were launched in the summer of 2007. These models include some of the latest innovations in automobile products especially apparent in the body structure, which features newly-developed material grades and utilizes some of the latest production technology.

2 THE BODY CONCEPT OF THE VOLVO V70 MODEL

The V70 body is based on the EuCD platform jointly developed by VCC, Ford of Europe (FoE) and Jaguar/LandRover (JLR). This means that the platform is not only the base for the Volvo models S80, V70 and XC70, but also for the Ford Mondeo, Ford Galaxy, Ford S-Max and Land Rover Freelander.

In keeping with Volvo's reputation for safety, the V70 model includes some advanced safety features such as Blind Spot Information System (BLIS), Driver Alert Control (DAC), Lane Departure Warning (LDW), Adaptive Cruise Control (ACC), etc. However, all these devices have to be supplemented by an integral safety cage structure (Figure 1) with dedicated crush zones for optimum energy absorption in the event of a collision. To achieve such stringent requirements, and at the same time avoid severe weight penalties, proved to be a real challenge during the engineering of the new Volvo V70.

Besides specific technical innovations such as hydroformed frontal crash cans, integrated crash boxes for the rear bumper beam and the world's first hot-stamped B-pillar with patch reinforcement, a careful material upgrade was carried out. This meant that typical Re-phosphorized and HSLA (High Strength Low Alloy) grades were substituted with DP (Dual Phase) and hot-formed sheet components. With such an approach, it was possible to improve the body performance without adding unnecessary weight, something which is

Figure 1 – The safety cage structure of the new Volvo V70 model and the function of the supplementary restraint systems (SRS); frontal air bags (FAB) and inflatable curtains (IC)

desirable from an environmental standpoint. Low body weight makes it possible to reduce fuel consumption as well as hazardous combustion emissions. Body performance is generally expressed through the term LBCI (Lightweight Body Construction Index), where the body mass is divided by the product of global torsion stiffness and the projected area of wheel base, times track width. As the lowest LBCI-value as possible is desirable, comparison of the previous V70 model of the year 2000 with today's product reveals that this figure has decreased from 4.95 to 3.88 [kg/(kNm/° × m²)].

2.1 Material grades

As previously mentioned, a comprehensive material upgrade was performed during the development of the new V70 model (Figure 2). This meant that the amount of mild steel parts with yield strength below 180 MPa had decreased from 57.7 weight-% of the total body mass to 30.5 % when compared with its predecessor. HSS (High Strength Steels) with yield strength in the range of 180-280 MPa have been kept more or less constant, constituting around one third of the body mass, whe-

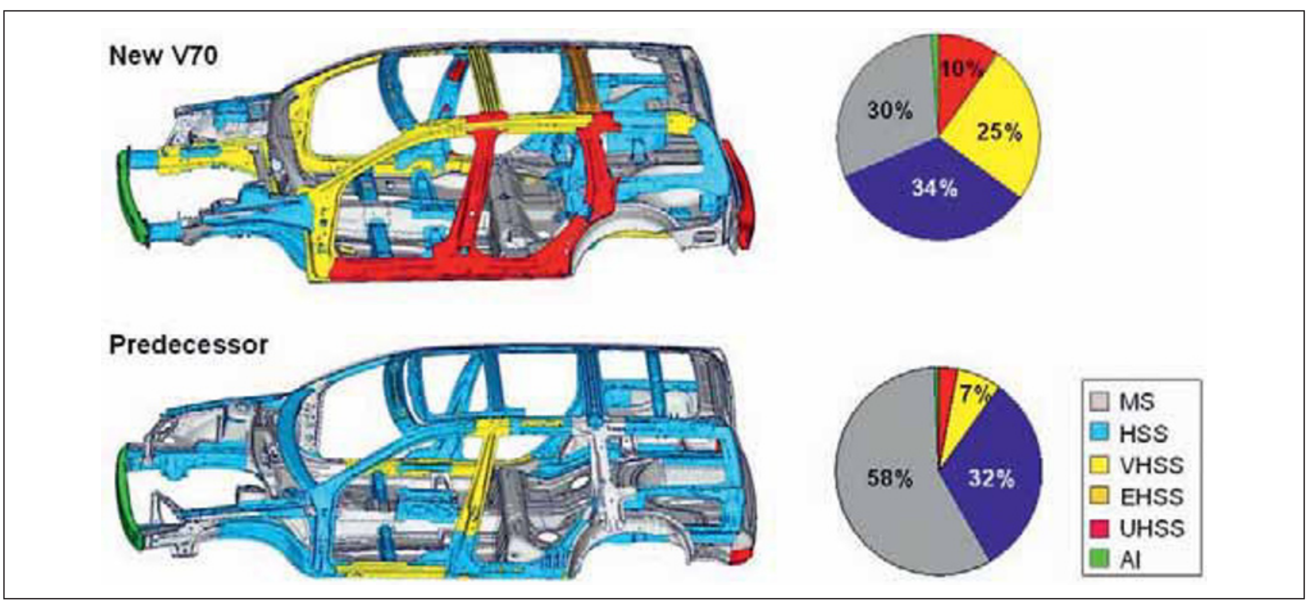


Figure 2 – Comparison of material grade distribution between the new Volvo V70 and its predecessor

reas high strength grades between 280-380 MPa in yield strength have increased from 7 to 25 weight-%. These parts are mainly comprised of DP600 materials (Dual Phase grades with an ultimate strength of 600 MPa), but one particular part, the roof bow connecting the C-pillars, is manufactured with a 0.7 mm thick, zinc-coated TRIP700 (TRansformation Induced Plasticity material with R_m = 700 MPa). However, the most pronounced development regarding material upgrade concerns the hot-formed boron alloyed parts with tensile strength in the order of 1 500-1 600 MPa. In the previous generation of V70s, only the rear bumper beam was manufactured using this Ultra High Strength Steel (UHSS) material, but now similar material is used in the floor sill, the C- and B-pillar reinforcements. For the latter, yet another boron alloyed piece is integrated through patch technology (see section 4).

2.2 Joining methods

In comparison with the old generation of V70s of the year 2000, two completely new joining methods have been introduced with the launch of the new body version. Approximately 40 metres of structural adhesives (both epoxy and rubber-based compositions) have been introduced. This is a carry-over solution from the S80 model launched the year before [1]. The main contribution of these adhesives is improved crash performance, rigidity and endurance. The other assembly method making its début is laser brazing. The main reason for choosing this technology to attach the “ring-frame” to the body sides was to achieve superior design, craftsmanship and optical quality [2]. The brazing operation is performed by two articulated-arm, robot-manipulated tools, connected by optic fibres to a 3 kW diode-pumped Nd:YAG laser. Moreover, the amount of laser welding has been increased from 3.7 to 5.7 metres when compared with the V70 predecessor. Through the addition of the continuous joining methods mentioned, it has been possible to decrease the number of resistance spot welds (RSW) from 4 595 to 4 170 (Table 1). However, due to the introduction of new grades of high strength steels and several difficult-to-weld combinations, it was necessary to perform extensive spot welding trials during the pre-development phase and prototype construction, as well as during machine tests. A more detailed description follows about the working procedures and other actions and activities necessary to establish high spot weld quality, before launching high volume series production of the new, high strength steel body concept of the Volvo V70.

3 THE PROCESS OF HOT-STAMPING OF ULTRA HIGH STRENGTH STEELS

Press-hardening or hot-stamping and die-quenching is a method used to produce ultra high strength components for the automotive industry. Typical components produced by the press-hardening process are e.g. A- and B-pillar reinforcements, side impact door beams and bumper beams.

The press-hardening process was developed almost 30 years ago by the company SSAB (Swedish Steel Co.), in conjunction with the Luleå Institute of Technology. The steel grade most commonly used is a boron alloyed steel corresponding to 22MnB5, either un-coated or AlSi pre-coated. Table 2 shows a typical chemical composition.

Figure 3 shows a general outline of the direct press-hardening process. Firstly, blanks are cut from a strip. In most cases, the shape of the blank is adapted so that the hot-formed and quenched component will receive its final shape without the need for any subsequent adjustment of shape or dimension. Necessary holes in

Table 1 – Joining methods used for the assembly of the Volvo V70 body structure

Type of joining method	Amount	
	V70 YM* 2008	V70 YM* 2001
Resistance spot welds	4 170	4 595
GMA** welding	5.5 m	4.6 m
Laser welding	5.7 m	3.7 m
Laser brazing***	1.3 m	-
Epoxy-based adhesive	24.9 m	1.1 m
Rubber-based adhesive	16.2 m	-
Hot melt sealant	19.8 m	30.5 m
Vibration damping “anti-flutter”	2.8 m	2.4 m

* YM = Year Model.
** GMA = Gas Metal Arc (shielding gas composition 77 % Ar + 23 % CO_2).
*** CuSi3 filler wire.

Table 2 – A typical chemical composition of the boron alloyed 22MnB5 steel

C	Si	Mn	P	S	Cr	Al	Ti	B
0.23	0.20	1.15	0.010	0.002	0.20	0.040	0.030	0.0030

All values are in weight percent.

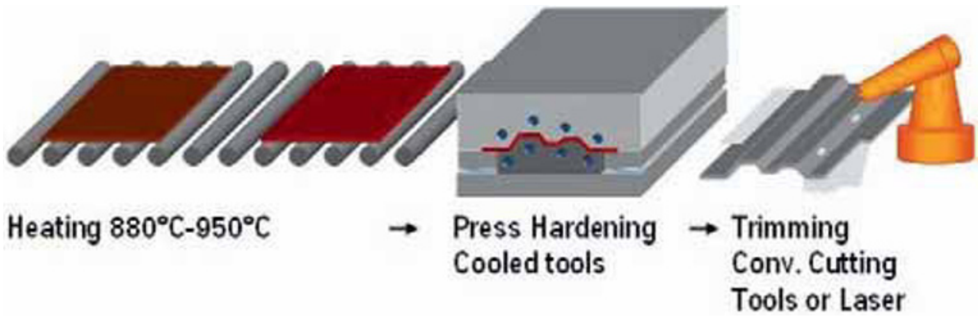


Figure 3 – Description of the direct press-hardening process

the component are also pre-punched. The blank is then heated to approximately 920 °C. The length of heating time is chosen so that the blank will be fully austenized. For the un-coated boron steel, the furnace atmosphere is adapted so that neither oxidation nor surface decarburization will appear. The hot blank is thereafter placed in the hot-forming tool and formed. The forming dies, which are water-cooled, are held together long enough for the formed component to be cooled to a temperature well below the martensite finish temperature (the M_f temperature). The cooling rate is fast enough for a martensitic microstructure to be obtained.

If the component is made of un-coated steel, an oxide scale will form on the surface between the time the blank exits the furnace until the forming dies enclose the component, i.e. when the hot blank is exposed to air. This oxide scale is commonly removed by shot-blasting but can also be removed by pickling. Since no such oxide scale is formed on components made of AlSi pre-coated boron steel, shot-blasting or pickling is therefore not required, thus presenting a more cost-effective alternative.

Some components may have such a complex shape, such as holes located in areas which are highly deformed during hot forming, or very narrow dimension tolerance requirements, that a post-punching operation is required. This can be executed either by laser-cutting or by die-punching.

Table 3 presents typical properties obtained by the press-hardening process. Since the component is formed in a hot condition, re-crystallization will appear during the forming process. The properties will therefore be uniform within the entire component and the residual stresses within the component will be very small.

Table 3 – Typical mechanical properties of a press-hardened component made of boron alloyed steel corresponding to 22MnB5

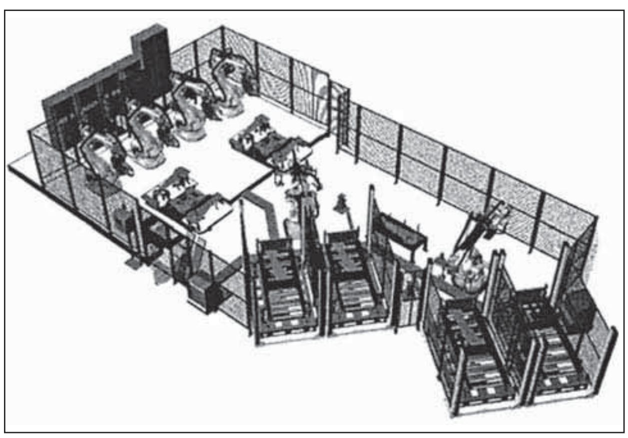
Yield strength* [MPa]	Tensile strength [MPa]	Elongation** [%]
1 100	1 550	5 - 7

* Proof strength, 0.2 % extension.
** Percentage of total elongation, 50 mm original gauge length.

4 CONSIDERATIONS OF SPOT WELDING AT PATCH TECHNOLOGY

The reinforcement part of the B-pillar solution for the V70 models is made of a patch-reinforced blank that is press-hardened. The small patch and the large main blank are joined by 46 spot welds and the spot welding operation is carried out in a robot-assisted production cell (Figure 4). Four of the robots in the cell are equipped with servo motor-driven welding guns and adaptive weld timers are used to control the welding operation. Each blank is welded by two robots which means that two blanks can be welded simultaneously in the cell. B-type welding caps with a diameter of 20 mm are used and an electrode tip dresser is connected to each welding gun. 320 spots are welded during two consecutive dressing operations and the electrode caps are dressed 25 times before they are replaced. The production rate is approximately 13 000 B-pillar reinforcement blanks per week. The V70 B-pillar reinforcement blank consists of a 1.4 mm thick blank to which a 2.0 mm patch is welded. Both parts are made of un-coated 22MnB5 boron alloyed steel. The parts are cut from cold-rolled, non-annealed strips and welding is conducted before the patch-reinforced blank is heated, hot-formed and cooled.

The following are checked regularly:
– General appearance of the B-pillar reinforcement blank.
– Number of spot welds on each reinforcement blank.



The welding guns are mounted on the four robots on the left of the cell.

Figure 4 – Spot welding cell

a) Upper control hole for exact positioning of the patch blank

b) Cross section through a spot weld with 7.0 mm diameter and moderate electrode indentations

Figure 5 – The upper part of the reinforced blank for the V70 B-pillar reinforcement

– Position of each separate spot weld.
– Distance between spot weld centre and the edge of the patch.
– Occurrence of spatter.
– Surface cracks in or close to the weld cap indentation.
– Penetration depth of the spot weld.
– Weld nugget diameter.

The general appearance of the welds, number of spot welds, occurrence of spatter and appearance of cracks are checked visually. The position of each spot is chekked with the help of a template. The nugget diameter is checked on specially-designated coupons. All these checks are conducted by the welding cell operator. Figure 5 shows the upper part of the reinforced blank with a cross section through a spot weld.

An example of a finished component can be seen in Figure 6. Here, the majority of the spot welds in the middle area (the top area) are located in positions that are not strained during the hot-forming operation. However, spot weld positioning may be a concern, therefore comprehensive simulation exercises were performed in order to find the optimum location for the spot welds. Some of the welds located on the web side and near the upper end of the blank are deformed during the hot-forming process. Figure 7 shows one such spot weld (circled). Due to the deformation during the hot-forming operation, the original circular electrode indentation has become oval. The adjoining cross-section however reveals that there are no internal defects in the weld. In fact, no defects have been found in the spot welds that are located in areas where the blank is heavily deformed during the hot-forming operation.

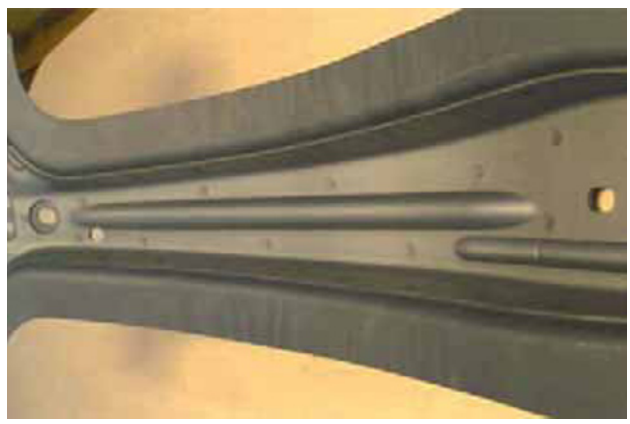


Figure 6 – The upper part of a press-hardened B-pillar reinforcement for a new Volvo model intended for start of production (SOP) in autumn of this year

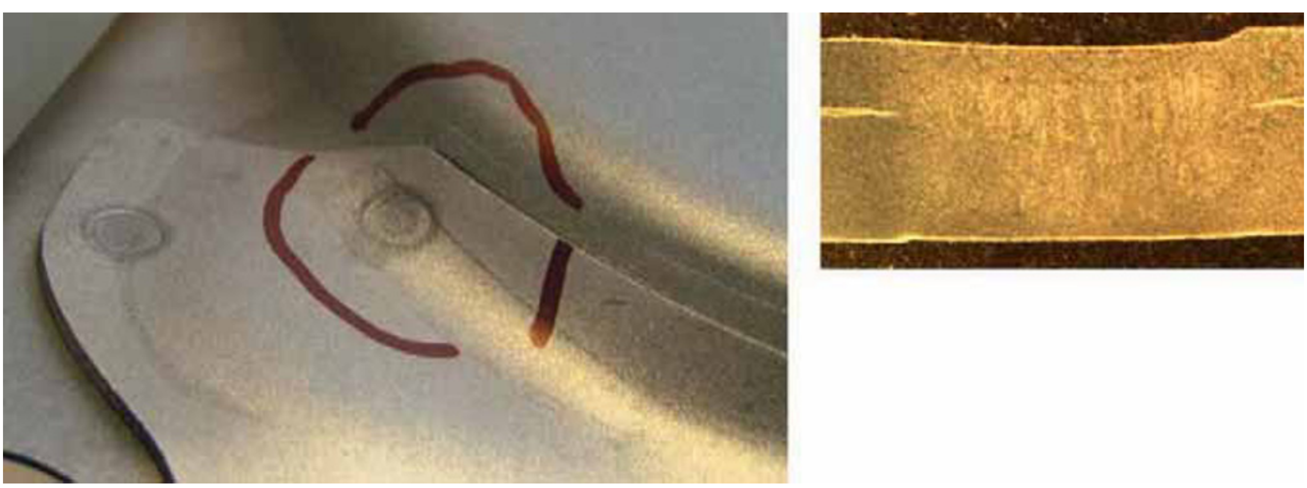


Figure 7 – A spot weld that is deformed during the hot-forming process with corresponding cross-section on the right

The afore-mentioned forming simulations indicated that four spot welds at the lower part of the patch blank were situated in an area with large deformation during the hot-forming operation. This was later verified through actual forming which showed that the main blank cracked around two of these welds. In order to avoid this, these two welds were welded after the B-pillar had been formed, hardened and shot-blasted. Such lessons learnt are now considered during the design process for other ongoing VCC projects, meaning that no highly-deformed spot welds will occur.

5 PROCESS AND PRODUCT VALIDATION OF SPOT WELDED HIGH STRENGTH STEEL MATERIAL COMBINATIONS

The new ultra high strength steels are presenting the welding engineer with new challenges, i.e., smaller welding windows (less robustness), more complicated fracture mechanism, potentially weaker welds, different fatigue behaviour and more complex quality checking in production. The classic problems such as alignment, the presence of adhesives and sealants as well as various types of zinc coatings, might also have a greater effect on the welding of UHSS as compared with conventional mild steels. This increases the demand for and complexity of weldability testing, performed in the early project phases.

The weldability test is a phase in every new car project. VCC welding engineers receive sets of material combinations which have not been tested before and no previous test with similar sheet combinations contains information sufficient for an appropriate judgement of weldability (Figure 8). After a weldability test, the following should be known:

– The demands according to standards, i.e., nugget diameter, penetration, indentation, etc..
– Size of the welding window, in order to validate the robustness of the process.
– Expected types of fractures at destructive testing.
– Static, fatigue and dynamic strength of the weld.
– Initial parameters for the weld timer, i.e., electrode force, welding time, welding current, possible pulsing required, etc.
– Demands for equipment, i.e., AC (Alternating Current) or DC (Direct Current), type of welding gun, electrode cap size, if an adaptive weld timer must be used etc..

The range of testing is, however, often related to the "newness" of the UHSS material. Static strength of the welds is usually tested, but fatigue tests are more rare. The main focus of the welding engineer is to find welding parameters which result in a robust production process. To evaluate a welding window, a one-dimensional (1-D) welding lobe is measured. Figure 9 shows a typical 1-D lobe, where the nugget diameter is recorded as a function of the welding current, while the welding time and electrode force are kept constant. These tests are conducted on small coupons, 125 × 38 mm, which can easily be peeled shortly after welding in order to validate the nugget size. These coupons are also used for the static test and are sufficiently large for the appli-

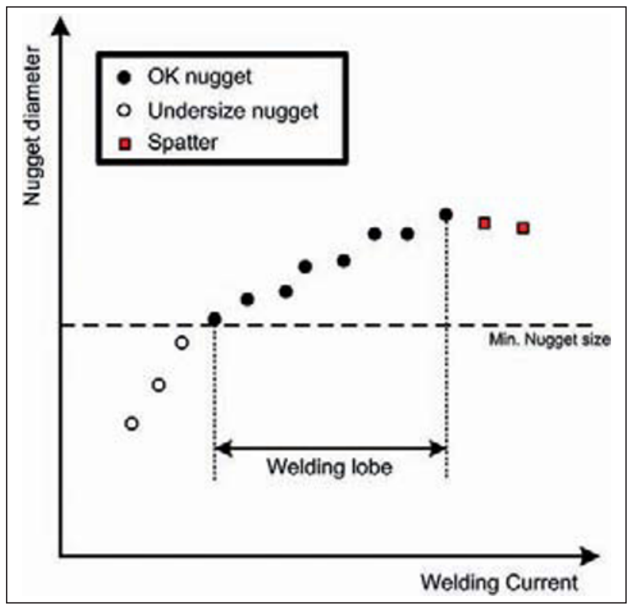


Figure 9 – 1-D welding lobe showing the nugget diameter growth in relation to increased welding current

Project	Material 1	Material type 1	Thickness mtrl. 1	Coating 1	Adhesive mtrl. 1,2	Material 2	Material type 2	Thickness mtrl. 2	Coating 2	Adhesive mtrl. 2,3	Material 3	Material type 3	Thickness mtrl. 3	Coating 3	Nugget VCC std
V70 XC70	V-1478	DP600	1,65	Z140		V-1568	Boron	1,40	Blasted		V-1159	MS3	0,77	Z100	4,5
V70 XC70	V-1478	DP600	1,65	Z140		V-1568	Boron	1,00	AlSi						4,5
V70 XC70	V-1478	DP600	1,4	Z140	x	V-1568	Boron	1,30	AlSi	x	V-1568	Boron	1,40	Blasted	6,0
V70 XC70	V-1159	MS3	1,5	Z100		V-1568	Boron	1,30	AlSi		V-1568	Boron	1,00	AlSi	4,5
V70 XC70	V-1478	DP600	1,4	Z140	x	V-1159	MS3	1,25	Z100		V-1568	Boron	1,30	AlSi	6,0
V70 XC70	V-1478	DP600	1,4	Z140		V-1568	Boron	1,30	AlSi						6,0
V70 XC70	V-1478	DP600	1,65	Z140		V-1478	DP600	1,40	Z140	x	V-1568	Boron	1,20	AlSi	6,0
V70 XC70	V-1478	DP600	1,4	Z140	x	V-1568	Boron	1,30	AlSi		V-1478	DP600	1,50	Z100	6,0
V70 XC70	V-1159	MS3	0,77	Z100		V-1568	Boron	1,40	Blasted		V-1159	MS3	1,25	Z100	4,5
V70 XC70	V-1423	HSLA	1,20	none		V-1159	MS3	1,25	Z100		V-1568	Boron	1,40	Blasted	6,0
V70 XC70	A351-A2	Trip700	0,70	50G50G-HD		A322-A3	Boron	1,00	AlSi						4,5
V70 XC70	A351-A2	Trip700	0,70	50G50G-HD		A348-A5	DP600	1,60	50G50G-HD		A322-A3	Boron	1,00	AlSi	4,5

Figure 8 – Excerpt from a list showing material combinations for the V70 car body included in the weldability test program

cation of adhesive or sealant, if such is required. A few years ago, hat profiles were used in the 1-D lobe trials, but the increased use of UHSS has made such test objects too difficult to produce, due to the strong spring-back of these material grades.

The first step when conducting a 1-D welding lobe test is to estimate the electrode force and welding time as start values for the test. These values are calculated with given formulae and tables, based both on production experience and on recommendations from equipment suppliers. The values can be easily calculated and are therefore also used for process simulations, where welding time affects the cycle time and the electrode force influences the dimensions of the welding gun. Today, these estimates for welding time and electrode force usually result in a satisfactory welding window, i.e., larger than 1.5 kA. It may be possible to adjust the welding time and force to obtain a larger welding window, however, if the welding lobe is sufficient with the initial values, no further optimization is done. The 1-D lobe welding trials are always done with CCR (Constant Current Regulation) as no routine exists for the moment, making it possible to evaluate weldability with an adaptive weld timer.

After an acceptable welding window has been obtained, samples for static tests, cross-section analysis, hardness measurement and other tests are welded. The current is set for fulfilment of the minimum nugget diameter requirement. The fracture mechanism of the nugget is often seen in samples from static testing. Interfacial fractures (IF) are more frequent when UHSS material is welded, especially at the low current region of the welding window. The strength of the weld must be sufficient even if an interfacial fracture occurs, otherwise it is not accepted. The fact that IF fractures are more common near the lower limit of the welding window means they are less frequent in the destructive tear-down test at the production site. This is due to the fact that welding parameters for running volume production are selected in such a manner, that a certain margin for the specified minimum weld nugget demand is guaranteed, which leads to a simplified interpretation of the nugget size. After testing has been finalized, the welding engineer creates a test report in which all above-mentioned items are recorded.

One of the major challenges in resistance spot welding of the new V70 and XC70 models was the increased use of boron alloyed steels. While this material is not a heavily alloyed multi-phase material, it is the surface conditions that create major problems for the spot welding process. The hot-forming process leads to the formation of a thin oxide layer on the surface, usually referred to as a scale. This scale must then be removed and is today usually achieved by a shot-blasting operation. Other options previously used were the etching or pickling of the surface. However, these are expensive and environmentally unfriendly processes and therefore, less suitable.

One of the characteristics of a shot-blasted surface is the variation of the electric resistance of the surface. This can vary both between components, as well as within the same component. The variation of the electric resistivity of shot-blasted surfaces is sufficient to disturb the spot welding process and significantly decrease the weld quality of a conventionally-welded spot. Previously, pickling the oxide scale off the surface solved this problem, but this is no longer an option. Today, there are two main solutions, one is the use of AlSi-coated material which prevents scaling; the other is the use of an adaptive weld timer. Both solutions were applied in the V70/XC70 project. The use of AlSi-coated material is the simpler solution since conventional weld timers can then be adopted. However, AlSi-coated material is very difficult to weld with robotized gas metal arc, which excluded AlSi material from some of the current applications.

For all of the sheet combinations containing boron alloyed steel tested for V70/XC70, there was no need to adjust the welding time proposed at the outset. The adaptive weld timers used in the project recommend relatively long welding times which work quite well. The adaptive timers managed to compensate for the variation in surface resistance caused by the shot-blasting cleaning process. The well-known problem of large thickness ratios did not cause any unforeseen problems. Figure 10, from the laboratory testing, shows how the diameter of the nugget was smaller at the thin sheet side in a three metal stack-up. These parameters, obtained at coupon welding with MFDC (Medium Frequency Direct Current ~ 1 000 Hz), worked well, together with the adaptive timer for sheet combinations containing two thick sheets and one thin.

6 HIGH PERFORMANCE SPOT WELDING EQUIPMENT FOR HIGH VOLUME CAR BODY ASSEMBLY

As previously outlined, the new Volvo V70 model contains an increased amount of UHSS materials, with a high content of shot-blasted boron steel and an increased usage of epoxy-based structural adhesives. Therefore, the complexity of spot welding and monitoring of the process have increased and made it necessary to re-build the body assembly line at the Torslanda plant, introducing some of the newest technology and equipment available. When starting the EuCD program with its forerunner, the new Volvo S80 luxury sedan, it was decided to use adaptive weld timers to take care of possible disturbances (Figure 11). With the help of such a system it is not only possible to get more benefits than just reacting to disturbances, but also to manage monitoring of the welding process and its condition at the same time.

Adaptive weld timers work in such a way that the system measures resistance in the equipment itself and in the sheet components to be welded, as well as compares the voltage curve to a calibrated one. The system reacts either by increasing the current or pro-

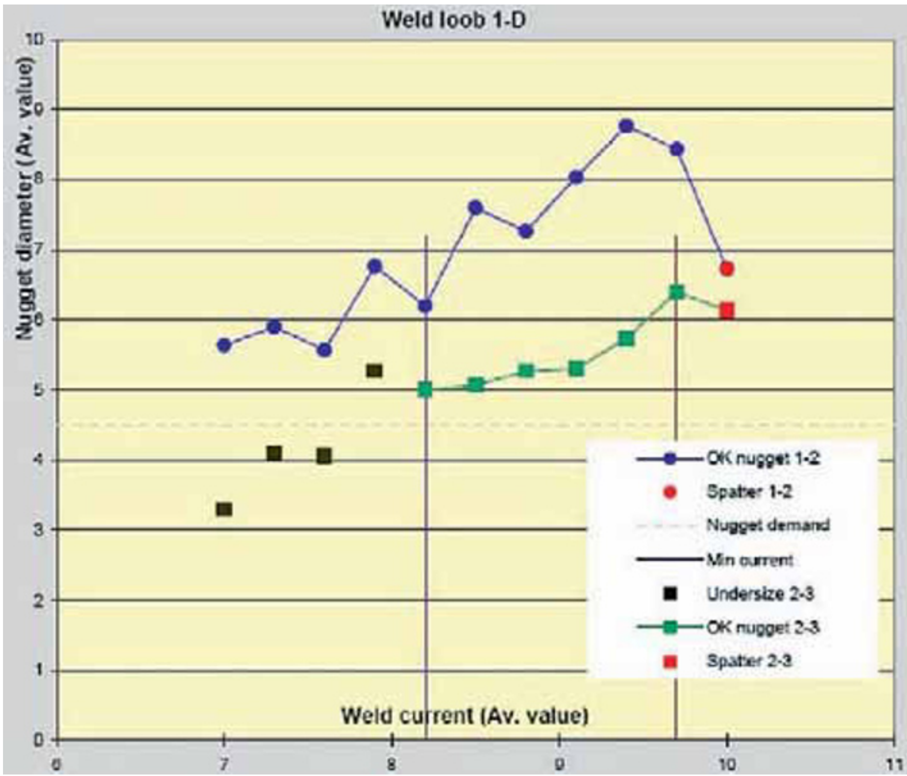


Figure 10 – The welding lobe of a three-sheet combination consisting of DP600 (1.65 mm), boron steel (1.4 mm) and a mild steel (0.77 mm)

longing the welding time, if there are any deviations from the nominal values (Figure 12).

Calibration is normally carried out at coupon level, which makes it possible to generate calibration curves in advance, before going into full-scale prototype construction. Sometimes, complete car bodies are used in order to get a more accurate calibration. The drawback is that it will be harder to determine whether weld nuggets are good enough if the tearing down of numerous car bodies solely for calibration purposes is not allowed. The downside to performing calibration on

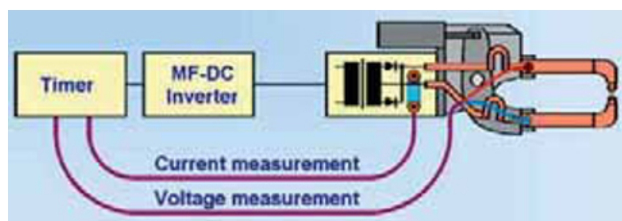


Figure 12 – Principle sketch of a weld timer arrangement with current and voltage measurement

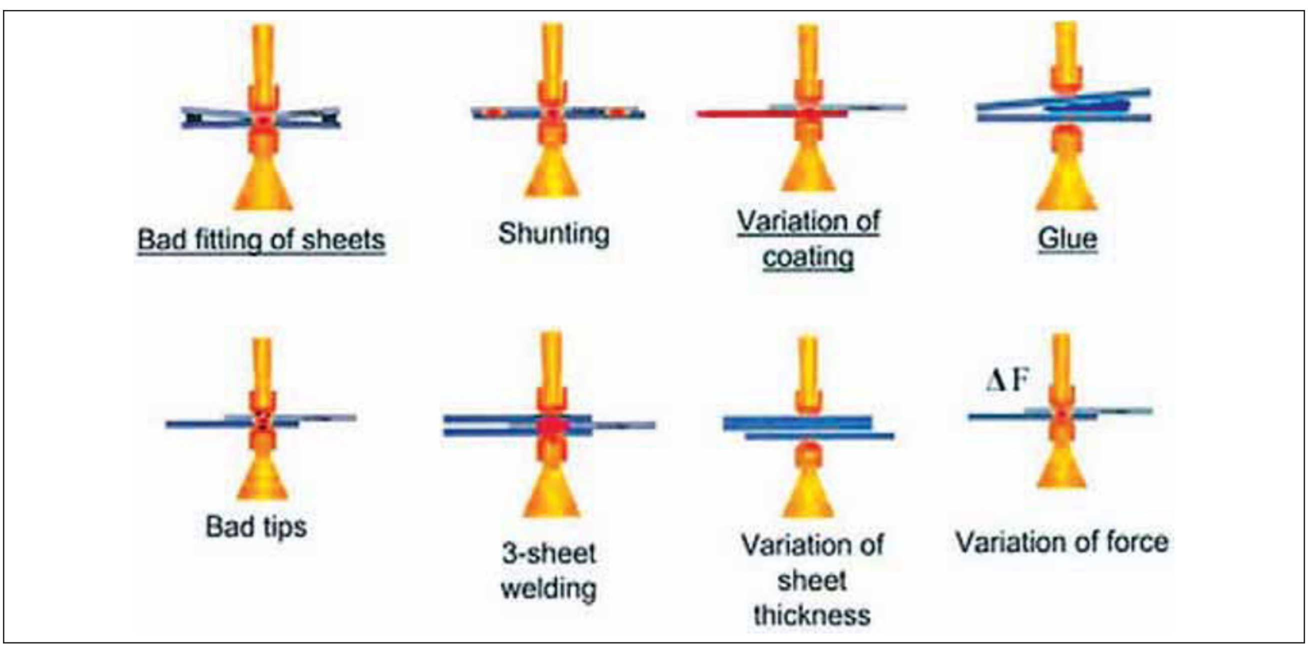


Figure 11 – Examples of possible causes for poor weld quality which can be counteracted by a spot welding gun which utilizes an adaptive weld timer

coupons is that one needs to have a large stock of different coupons (thickness and material grade), as well as the fact that there are various logistical requirements involved in the handling of coupons. This could result in the delivery of the wrong coating/material/thickness, or quite simply, the mixing up of the different coupons.

At the same time that the decision was made to use new weld timers, the plant also invested in a large number of electric servo guns and several tests were made in order to prepare for the new F-packs (Functional packages = robot + timer). The main reasons for choosing the electrically-driven gun were the increased speed and the accurate movement afforded (Figure 13), which in turn reduced the number of F-packs needed. This implied a substantial economy for the new assembly line. For a framing station, time saving can be up to 30 % and for a re-spot ditto, it is 10-12 %, which represents the total time required (welding + movement). For the welding time itself, one can save 300 ms/spot just from a reduced squeeze time.

In the first tear-down test, during pre-series construction, it was possible to establish that 95 % of the spot welds were acceptable. Here it should also be pointed out that some of the NOK spots were related to bad robot positioning, such as edge welds or "welds-in-welds", something which cannot be influenced by the adaptive timer system.

Today, the output from the body shop is in the range of 98-99 % acceptable spot welds and the next step in quality improvement will be to run a weld spatter optimization program. For that reason, the calibration curve will be done on the first spot in the weld sequence and not on the second as is currently done. The main reasons for this approach are getting the weld nugget closer to the minimum acceptable diameter, while avoiding spatter contamination and also saving a substantial amount of electrical energy.

The numbers of new pieces of equipment installed in the EuCD line at Torslanda for the flexible production of the V70, XC70 and S80 models are summarized in Table 4.

7 NEW ASPECTS ON THE QUALITY ASSURANCE OF SPOT WELDS

For quality assurance of spot welds in high volume series production, both destructive and non-destructive methods are used. Regarding the latter, chisel testing is a method generally used by automotive manufacturers, whereby a chisel is inserted between the sheets close to a spot weld. Poor welds and zinc soldering can be detected via this method after which the parts are re-adjusted to their normal position.

However, due to the high strength of boron alloyed parts, it has proven to be almost impossible to insert a chisel in the afore-mentioned manner. Therefore, other NDT (Non-Destructive Test) methods have to be considered, which in practice means that nowadays ultrasonic checking is the normal procedure for evaluating the spot weld quality in metal stack-ups involving one or more boron steel parts. However, the introduction

Table 4 – Production equipment in the EuCD assembly line

Robot equipment	Numbers
Pneumatic welding guns	161
Electric servo-welding guns	105
Bosch MFDC* inverters	152
Bosch adaptive inverters	27
Matuschek adaptive inverters	80

* MFDC = Medium Frequency Direct Current

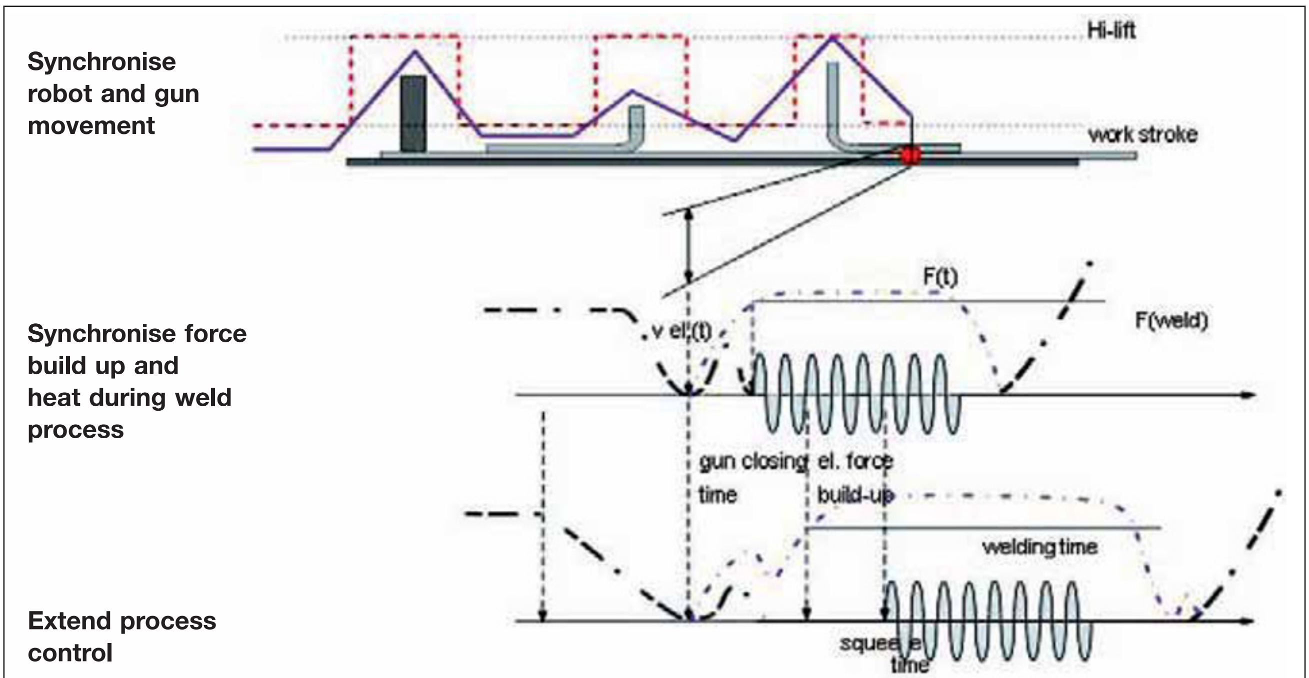


Figure 13 – The principal operation of an electric servo gun

of boron alloyed steels makes the use of ultra-sound measurements more complex, as compared with when the method is applied to mild steels. The occurrence of centre pores is more frequent, for example (Figure 14). Such pores are not classified as defects, but may easily be interpreted as other defects during ultrasonic chekking. To make the distinction between a good weld with a centre pore and a defective one requires skilled, well-trained operators.

Ultrasonic checking is also the preferred technique for other difficult-to-reach spot welds, resulting in 25 % of the 4 170 spot welds in the V70 body structure being quality-assured in this manner.

During the destructive testing which is done less frequently, other issues arose. These were already identified in 1998 when the previous S80 model was launched. The body of that model presented a rear bumper beam solution consisting of two 1.2 mm-thick, shot-blasted, boron steel parts spot welded together. If one was to follow the traditional acceptance criteria, which determine that a full weld plug should be torn out from one of the sheets, several spot welds connecting boron steel parts to other HSS components would be classified as “not approved”. Therefore, partial plug failures (PPF) and interfacial fracture (IF) had to be accepted, provided that a rough fracture zone could be detected. This, however, was revealed to be uncertain evaluation criteria, as the fracture surfaces were difficult to read even if a magnification device was used. Therefore, a new requirement, the so-called “weld penetration depth”, was established. To validate this type of demand, a section cut analysis of crucial welds was necessary (Figure 15). A minimum weld penetration of 40 % of the sheet thickness was required for 2-sheet metal stack-ups and a corresponding 30 % of the thickness for the outer panels in a 3-sheet stack-up.

8 SUMMARY AND FUTURE PERSPECTIVES

This paper clearly demonstrates the necessity for an extensive pre-trial program regarding weldability/assembly of new material grades for the car body structure. Apart from the spot welding activities described here, similar measures are taken for laser welding, adhesive bonding and mechanical joining techniques like clinching or riveting, with the two latter techniques applying mainly to hang-on-parts (HOP) such as doors, bonnets, trunk lids and tailgates.

In Europe, there is a long-term commitment among automotive manufacturers to reduce the CO_2-emissions of their products to 120 g/km by 2012 [3] and to 100 g/km by 2020. This will, of course, greatly increase the need for weight reduction and for that reason, VCC has a long-term plan for how this should be achieved. Without affecting the platform solution, there maybe another 30 kg to be saved by the implementation of an upper structure, consisting of an aluminium roof panel and a load-carrying structure made entirely out of UHSS. For further weight saving, the underbody, which represents 65 % of the overall body mass, must be affected and new lightweight materials such as aluminium and magnesium will be mixed with different grades of extra high strength steels (EHSS).

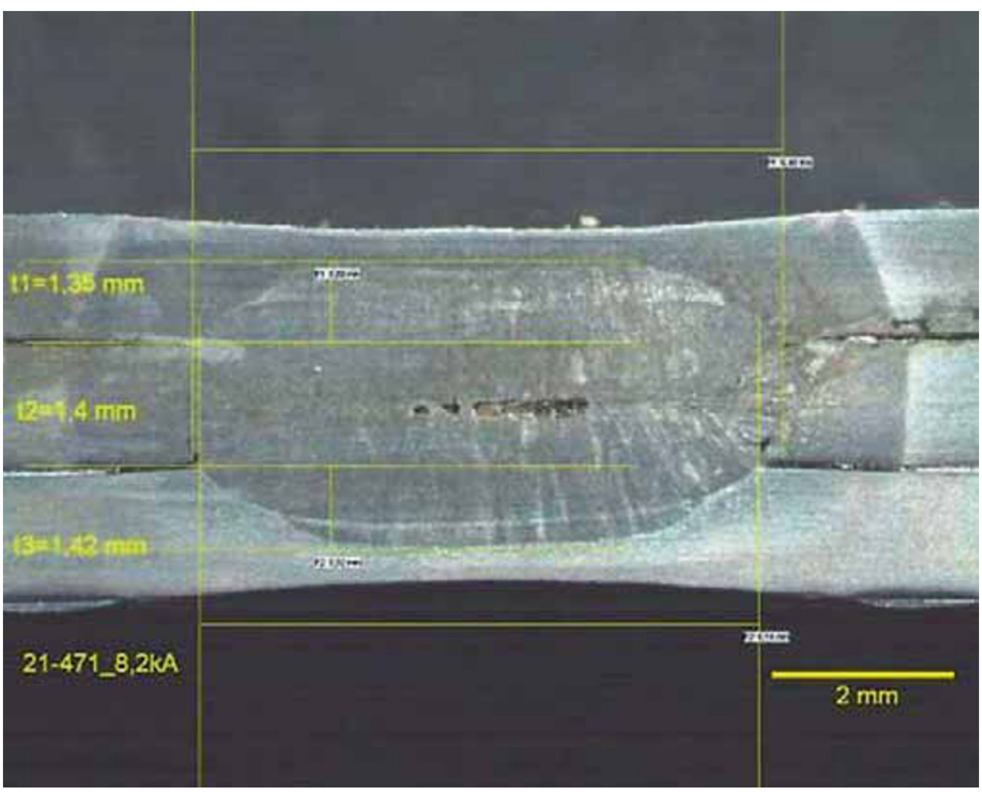


Figure 14 – Small centre pore in a boron alloyed steel sheet combination

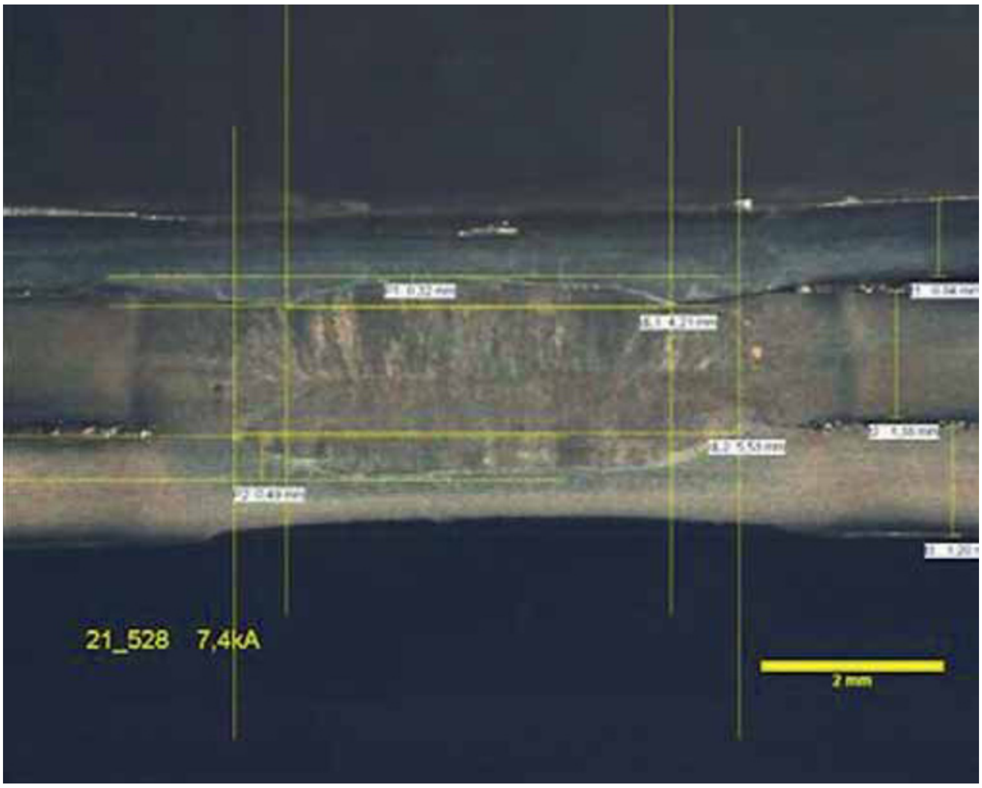


Figure 15 – Cross section analysis of a 3-sheet metal stack-up indicating sheet thickness, nugget diameter and weld penetration depth

Such scenarios will require extensive testing, as well as large-scale reconstruction and new layouts for the body shops, in order to rapidly boost production speed at the launch of a new car model. Apart from the new material scenario that can be expected, such a development also includes the introduction of production methods like hydro-forming, roll-forming and the afore-mentioned patch technology, as well as advanced assembly methods like laser scanner welding and cold metal transfer (CMT) arc welding.

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