Agnieszka Kiszka, Tomasz Pfeifer

Technological investigation into variable polarity GMA welding of HCT 600X ZF 100 RBO high strength steel

Introduction

A recently observed development in modern methods of MIG/MAG welding is connected with searching for techniques adequate for joining materials sensitive to heat impact, and in particular, for welding thin-walled elements made of protective-coated steels, aluminium and magnesium alloys, nickel alloys etc. This direction of investigation results in the development of new solutions focused on new MIG/MAG welding equipment. The latest method of GMA welding is the application of variable polarity current to supply an electric arc. A number of companies have recently developed equipment which makes it possible to apply this new welding technology in practice (Fronius, Cloos, and OTC Daihen).

Instytut Spawalnictwa in Gliwice has carried out thorough technological investigation into variable polarity GMA welding of protective-coated thin sheets made of unalloyed steels [1-3]. The research has demonstrated that using variable polarity current makes it possible to obtain joints characterised by good quality and aesthetics. Modern welding equipment (DW 300 by OTC Daihen, Qineo Champ by Cloos) enables the production of butt, overlap and T-shaped joints of 0.8mm-thick (and thicker) sheets.

The article presents the results of technological tests of welding dual phase steel HCT600X ZF 100 RBO as well as the results of tests of the mechanical and structural properties of joints. The publication focuses on discussing the results of technological investigation into welding this steel due to its widespread use in the automotive industry. An example of an application of the steel is in the production of subassemblies of the latest Ford Fiesta model.

Characteristics and application of HCT600X ZF100 RBO steel

Steel HCT600XZF 100 RBO is intended for cold working. The minimum tensile strength is 600 MPa. The production of the steel involves properly conducted cooling after annealing from the temperature range in which ferrite and austenite phases coexist. The structure of the parent metals is composed of fine-grained polygonal or acicular ferrite with “islands” of martensite (5-40%). The structure also contains a slight amount of retained austenite.

Steel HCT 600X is characterised by a significant difference between strength and yield point (Rp0.2=350 MPa) and due to that is excellent for longitudinal forming. This material is a specific type of composite, consisting of hard and resistant martensite and ductile ferrite. The properties of the steel depend on the quantitative ratio of these phases and the size of ferrite grains. The material has been additionally coated with a zinc and iron alloy characterised by improved quality. The coating was applied by immersing the steel product in a bath containing a minimum of 99% zinc. Next, the sheet was subjected

Agnieszka Kiszka MSc Eng., Tomasz Pfeifer PhD Eng. – Instytut Spawalnictwa, Zakład Technologii Spawalniczych /Welding Technologies Department/

to annealing, as a result of which the iron diffuses through the zinc. As a result, a mat grey zinc-iron alloy layer is formed containing an iron content of 8-12%. This kind of steel is usually supplied in the state following oil passivation, the purpose of which is to provide further protection of the steel against corrosion. This material is used in the automotive industry, where it replaces mild steels and conventional high strength steels. The use of HCT steel in welded structures makes it possible to build a resistant, yet lighter frame [4].

Assumptions related to car safety require the application of high strength steel in such areas of the car structure which guarantee a specified level of impact strength during a collision. The areas in question are presented in Figure 1. The steel HCT 600 X is used in the production of a rigid ring reinforcing the sides of the bodywork, preventing the effects of side impacts. The layout of the car bodywork also presents the structure of a reinforcing frame, increasing the cabin strength in this area. The purpose of the structure is to dissipate energy released from the cabin area during a collision.

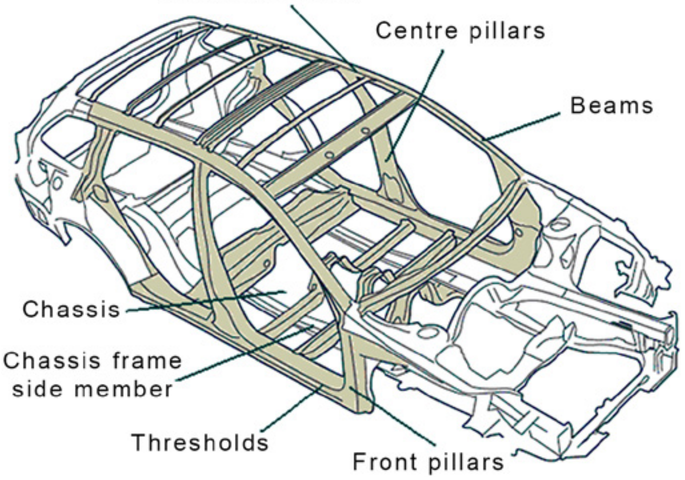


Fig. 1. Layout of car bodywork

The use of the steel in the car structure (frame side members, chassis) makes it possible to provide these structural areas with points, in which a crumple-utilising deformation begins. Such advantages as the ability to absorb collision-accompanying energy and resistance to deformation forces enable crumple (controlled deformation) favouring steel hardening.

Steel HCT 600X is also used for producing pushchair or bicycle frames (Fig. 2).

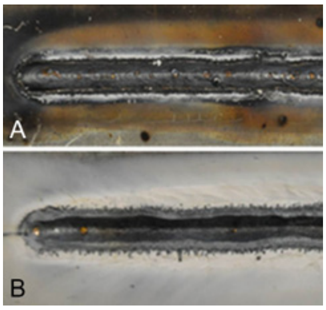
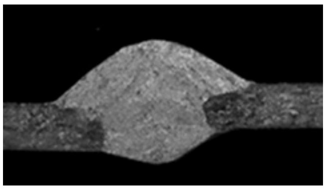
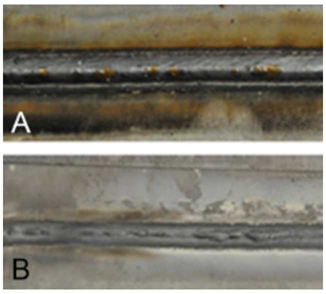
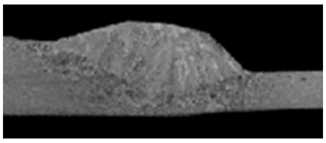
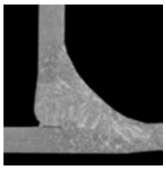
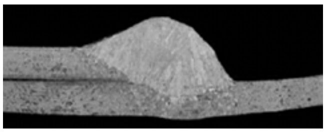
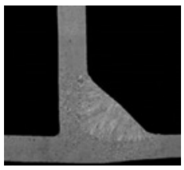
Fig. 2. Exemplary applications of HCT 600X ZF100 RBO steel

Technological tests

Welding tests of the steel were carried out on a mechanised station ensuring the repeatability of the welding process conditions. The tests involved the use of an electrode wire PN-EN ISO 14341-A-G3Si1 with a diameter of 1.0 mm and 1.2 mm. The shielding gas adopted for the AC Pulse welding was a mixture of 82% Ar +18% CO_2. In turn, the shielding gas used during Cold Process (CP) welding was a mixture of 92% Ar+8% CO_2. The difference resulted from the characteristics of the synergic line developed for each of the aforementioned welding methods. During welding the flow rate of the shielding gas was constant and amounted to 12 l/min. An additional process parameter is the electrode negative ratio (EN) in the welding current. This parameter, during AC Pulse welding, can be set within a range from -30 (the maximum EN ratio) to +30 (nondimensional setting). In turn, during Cold Process welding the parameter can be set within a range from 50 (the maximum EN ratio) to -50.

The welding technology tests aimed to simulate conditions present in the automotive industry. The tests involved the production of overlap, butt, T-shaped and also mismatched joints, as it is often necessary to weld sheets, whose accurate matching, guaranteeing the production of a high quality joint, is difficult.

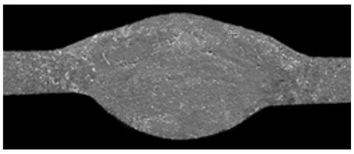
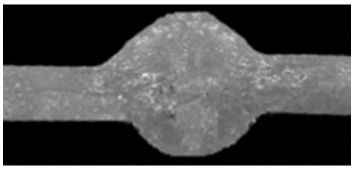
Table 1. Results of technological tests of variable polarity GMA welding of butt, T-shaped and overlap joints of steel HCT600X ZF100 RBO

Welding method	View of weld face (A) and root (B)	Joint macrostructure	Thickness of welded material (mm)	Electrode negative ratio
AC Pulse			1,0	0
				
			2,0	15
Cold Process (CP)			1,2	-20
			1,2	20
			2,0	
Remarks: etchant Adler				

The tests involved the use of 1.0 mm and 1.2 mm-thick sheets (overlap and butt joints) as well as 2.0 mm-thick sheets (butt and T-shaped joints). The methodology of the technological tests engaged the development of the most convenient welding parameters in view of quality, the production of individual types of joints, followed by visual and macro and microscopic metallographic tests, as well as tensile tests and hardness measurements.

The technological welding tests revealed that using variable polarity current makes it possible to obtain joints of good quality and aesthetics. Although the process of variable polarity GMA welding is less stable than traditional MAG welding and is accompanied by a specific sound, welded joints represent good quality and tend to be free from spatters.

Table 2. Macrostructures of mismatched joints of steel HCT600X ZF100 RBO

Welding method	Joint macrostructure	Thickness of welded material (mm)	Gap (mm)	En ratio in welding current
AC Pulse		1,0	0,5	0
			1,0	-20
Cold Process (CP)		1,2	0,5	
			1,0	
			0,5	20
Remarks: etchant Adler				

The basic process variables having the greatest impact on the process as well as on the weldability, quality and the aesthetics of joints are technological parameters (filler wire feeding rate, welding rate, torch inclination angle and arc length) and EN ratio in the welding current. A change of EN ratio significantly affects arc voltage and the amount of heat supplied to a joint. The research results revealed that the best effects are achieved with the zero setting of the parameter. An increase in EN ratio reduces penetration depth and bridging ability of an arc. If one needs to weld thin sheets and avoid, as much as possible, damage to a zinc coating, a higher EN ratio should be applied in the course of current. An increased EN ratio increases a heat input of the process as well as increases arc stability and penetration depth.

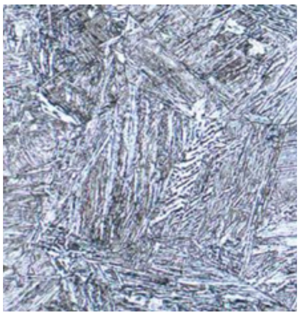
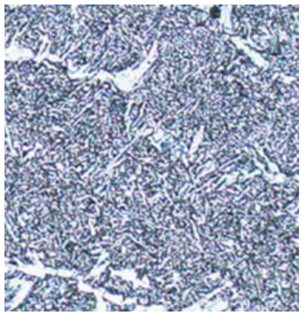
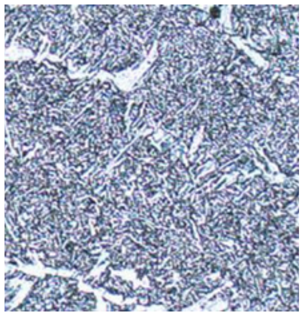
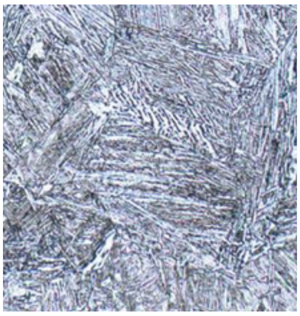
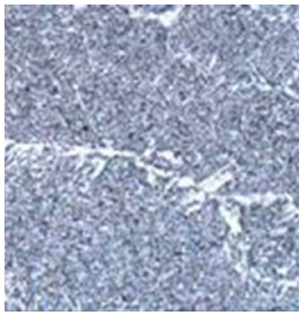
Therefore, it is possible to state that the methods under discussion can be used in the production of high quality joints made of high strength steel HCT600X ZF 100 RBO.

Welding mismatched joints

The next stage of the investigation aimed to determine the possibility of applying variable polarity GMA welding in joining inaccurately matched joints. Within the tests it was necessary to simulate conditions typical of the automotive industry, where one often encounters problems matching the edges of elements to be welded. The technological welding conditions were carried out using overlap and butt joints with a gap of 0.5 mm and 1.0 mm. Table 2 presents the macroscopic metallographic photographs of the obtained joints.

The conducted technological tests revealed that the low energy variable polarity GMA welding enables joining mismatched butt and overlap joints. It is possible to obtain good quality joints with a gap of 0.5 mm and 1.0 mm. The appropriate selection of welding conditions makes it possible to minimise or even entirely eliminate spatters. An increase in a gap requires EN ratio in the course ofthe applied current. As a result, an excessively convex face of the weld is obtained, yet the ability for bridging rises and the amount of heat supplied to the joint decreases (smaller penetration depth). An increase in the gap width deteriorates the weld quality and makes the welding process less stable. When the gap width exceeds 1 mm, it is no longer possible to make either an overlap or a butt continuous joint.

Table 3. Results of microscopic observations for selected joints made of steel HCT 600 X ZF 100 RBO

Welding technology	Structure of parent metal	Structure of HAZ	Structure of weld
AC Pulse	 Ferrite + martensite	 Martensite + slight amounts of bainite + slight amounts of granular ferrite	 Bainite + coarse-grained ferrite on boundaries of former austenite grains
Cold Process	 Ferrite + martensite	 Martensite + slight amounts of bainite + slight amounts of granular ferrite	 Bainite + coarse-grained ferrite on boundaries of former austenite grains
Standard pulsing arc	 Ferrite + martensite	 Martensite + bainite + very small amounts of ferrite	 Bainite + coarse-grained ferrite on boundaries of former austenite grains
Remarks: etchant Nital, magnification 200x			

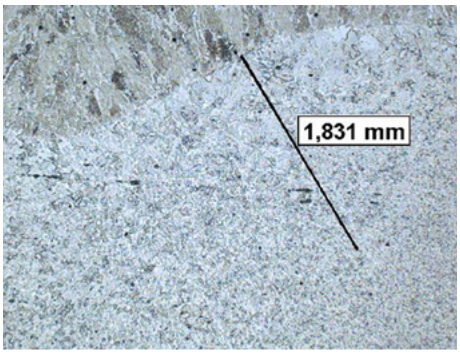


Fig. 3. Microstructure and HAZ width measurement result for the neutral EN ratio setting. Magnification x25. Etchant: Nital

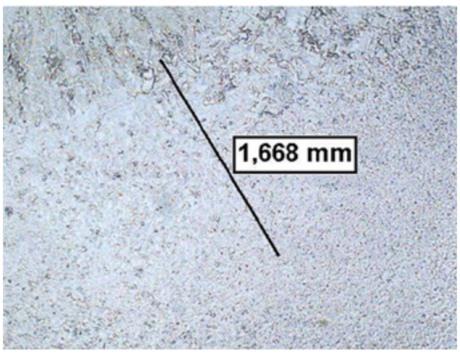


Fig. 4. Microstructure and HAZ width measurement result for the minimum EN ratio setting. Magnification x25. Etchant: Nital

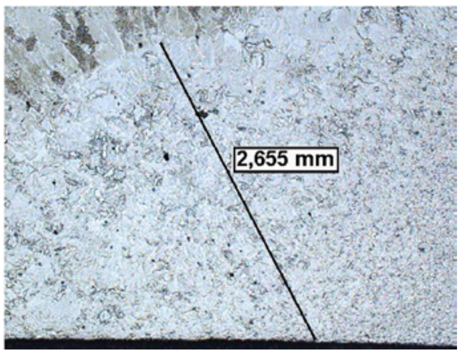


Fig. 5. Microstructure and HAZ width measurement result for the maximum EN ratio setting. Magnification x25. Etchant: Nital

Microscopic examination

In order to determine the impact of EN ratio in the course ofapplied current on the HAZ structure, it was necessary to make a number of padding welds at various settings of this parameter. Each padding weld was made of HCT 600 X ZF 100 RBO steel, on a separate sample (50 x 100 mm, 2mm in thickness). The technological parameters used during the tests were constant, only the value of the EN ratio changed. Afterwards the samples were used to prepare metallographic specimens for further tests. Observations were conducted by means of a light microscope LEICA MEF4M with a digital image analysis system. Microscopic examination was also carried out for selected welded joints (butt, overlap and T-shaped joints), made using the aforesaid low energy methods, as well as for the standard pulsing arc. The observations were carried out at 200x magnification, in the areas of parent metal, heat affected zone and weld. Figures 3-6 present the microstructure of the padding weld and HAZ for the neutral (zero) setting and the extreme settings of EN ratio along with HAZ width measurement results. The results of the microscopic metallographic tests of the welded joints are presented in Table 3.

The microscopic metallographic tests of the joints did not reveal the presence of any imperfections. No micro-cracks or gas pores were observed in any area of the joint. The weld structure is typical of welds made using electrode wire G3Si1 and is mainly composed of bainite with coarse-grained ferrite on the boundaries of former austenite grains. The structure of HAZ contains martensite with a slight amount of bainite. Therefore, it is possible to state that the structures obtained during the variable polarity welding of protective-coated high strength steels are typical of GMA welding.

Mechanical properties of welded joints

Another stage consisted in carrying out tensile tests and hardness measurements (Fig. 6) of selected joints. The joints selected for the tests were two butt joints with square preparation made of HCT 600X ZF 100 RBO steel, 1.0 mm, 1.2 mm and 2.0 mm in thickness. The test results are presented in Table 4. The results of the welded joints tests obtained for the same steel grade of the same thickness carried out by means of two different devices enabled direct comparison of the applied welding technologies.

The obtained test results revealed a slight increase in the weld hardness if compared with the hardness of the parent metal. The hardness in the weld is characteristic of the weld deposit hardness for electrode wire G3Si1. In the heat affected zone it was possible to observe a significant increase in hardness, probably caused by a partial

Table 4. Results of static tensile tests of butt joints

Welding technology	Material thickness (mm)	Rm (MPa)	Rupture spot
AC Pulse	1,0	628,2	Outside weld
		596,7	
		581,5	
	2,0	642,1	
		613,5	
Cold Process (CP)	1,2	601,5	
		567,7	
	2,0	590,4	
		592,5	
Remarks: min. Rm according to PN-EN 10346, PN-EN 10152 - 600 MPa			

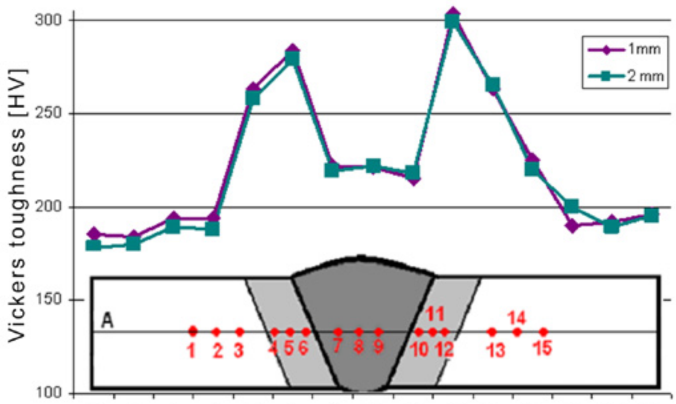


Fig. 6. Hardness measurement results for 1mm and 2mm-thick butt joints

structural change. All the obtained values are allowed according to standard PN-EN ISO 15614-1:2008. A small increase in hardness indicates that a welding process was carried out properly. The obtained results may also indicate that the structural changes which occurred in the HAZ during welding will not adversely affect the operating properties of the joints.

Summary

Applying innovative low energy variable polarity welding for welding HCT 600X ZF 100 RBO dual phase steel provided with a special zinc-iron protective coating makes it possible to obtain joints characterised by good quality and mechanical properties. The thickness of sheets used for the production of such joints must be within the range of 0.8 mm to 2 mm. Using variable polarity current and properly selected technological parameters (high EN ratio in the welding current enabling the reduction of heat energy)+- made it possible to produce high quality joints with minimum damage to the protective coating. The appropriate selection of process condition also enabled the minimisation or even the total elimination of spatters. The technological tests made it possible to develop a field of parameters enabling the production of mismatched joints with a gap of up to 1.0 mm. The analysis of the variable polarity welding process proves the usability of these methods in the production of high quality joints made of thin protective-coated sheets of HCT 600X ZF 100 RBO steel.

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