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Cold metal transfer (CMT) welding of thin sheet metal products

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Abstract. For welding of conventional structural steels semiautomatic technologies (MIG, MAG) are widely used, whereas for welding of Al-alloys and stainless steels the TIG welding method is the most common. The current study concentrates on welding of thin sheet metal products from stainless steel and aluminium by using a novel cold metal transfer (CMT) process. The CMT technology is an alternative to TIG, providing advantages, such as reduction of distortions and increased productivity. This is mainly due to low heat input, achieved by controlled movement of the electrode. In order to realize these advantages, optimization of the CMT welding process is essential. The aim of this study was the optimization of the process using the existing welding equipment (robot, manipulator, etc) and validation of the CMT process. The limiting factors for the increase of the productivity are the reduction of quality (increase of porosity, distortions and inacceptable shape of the welding bed). As a result, practical recommendations are given for the implementation of the CMT technology for robotic welding.

Key words: CMT process, welding automation, robotic welding, sheet metal.

1. INTRODUCTION

Analysis of welded products in industry shows an important share of welding thin sheet metal. During welding, temperature variations in welds and parent metals have important effects on material characteristics, residual stresses as well as on dimensional and shape accuracy of welded products. This is especially important in the case of thin sheet metal products, where control over welding distortions or deformations is difficult. Research, based on experimental, analytical and computational modelling methods, has been employed to investigate their effects induced on the welded structures for various applications of the conventional MIG process [1–2]. TIG welding process is well adapted to very thin products, making it possible to obtain high quality welds, with lower productivity than that of MIG. Welding speed is between 100–500 mm/min, although in automated welding higher speeds are possible [3]. The disadvantage of the TIG process is related to the difficulties to automate the welding process and lower welding speed compared to MIG. Novel welding processes with lower heat input, based on pulsed welding arc, may effectively be used for fabrication of sheet metal products, reducing the problems related to the MIG process. The CMT process is considered as a prospective welding process for sheet metal industry with narrow fabrication tolerances, high demands for product quality and high productivity. To improve quality, flexibility and productivity of the welding performance, the process automatization using welding robots is important. Available information about welding parameters of the CMT process is scanty, but it is essential for programming welding robots and creating welding procedure specifications (WPS).

The lack of qualified welding operators in today's labour market is a common concern of most Estonian metalworking industries. It has significant impact on the competitiveness of the metal-working industry. An obvious solution for lacking human resources is process automatization. In the past, robotic welding was considered applicable only in mass production, e.g., in automotive industry. Technology has undergone huge development during the past few years and nowadays rapid part changeovers and interchangeable tooling nests (or fixtures) enable automation even in companies, producing small batches of different parts [4].

CMT welding is considered to be a novel joining method that satisfies increasingly stringent demands, some of the most important of which are process stability, reproducibility and cost-effectiveness. Commonly, for welding thin sheets dip arc or short circuiting arc is used. The CMT process is based on controlled pulsed welding current and voltage and is basically a derivate of the well-known MIG/MAG process. Transfer of the filler metal to the welding pool takes place without applied voltage and current as shown in Fig. 1. The filler wire is constantly retracted at very short intervals. The precisely defined retraction of the wire facilitates controlled droplet detachment and gives a clean, spatter-free material transfer. The wire movement occurs with high frequency. About 70 droplets per second are detaching. Particularly noteworthy is the highly dynamic wire-feeder, mounted directly on the welding torch. The moment the power source detects a short circuit, the welding current drops and the filler wire starts to retract. One droplet is detached, with no or a few spatters. The filler wire then moves forward again and the cycle is repeated. High frequency and precise control over movements are the basic requirements for controlled material transfer. The wire drive on the welding torch is designed for speed, not for high tractive forces. The wire is therefore fed by a more powerful, but due to abovementioned facts, slower main wirefeeder. A wire buffer on the wirefeeding hose is used to convert the superimposed, high-frequency wire movement into a linear wirefeed [5].

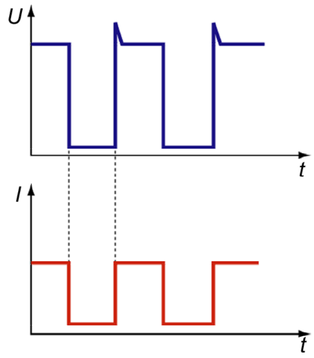

Fig. 1. Arc voltage and current in the CMT process.

CMT welding is conducted exclusively using digital inverter power sources. The welding system basically uses the same hardware as the MIG/MAG system, while considering certain specific requirements. CMT process is successfully implemented in automotive industry as robotic welding [6,7].

2. EXPERIMENTAL

In Estonia, the CMT process has been implemented by vocational schools and only by a few companies so far. Know-how and experience of applying this process is scanty. The program of the study was determined by demands and needs of the enterprises. A method of product analysis was established to get a better overview of products and create product families. Potential products for robot welding were analysed on the basis of technical drawings, quality requirements, production programs and materials used. Types of main welds, prospective for robotic welding, were determined. The testing plan is based on the prior analysis of the company product portfolio (material types and grades, thicknesses, joint types, etc) and possible application of the expected results in other companies with similar product portfolios. Different welding joints were fabricated at Favor Ltd, using the robot welding cell.

The robot welding cell, used in the study, comprises the ABB IRB 1600-6/1.45 welding robot, which has robotic arm reach of 1.45 m and 6 kg payload. The system is equipped with the Fronius TPS 3200 CMT power source and IRBP 250K manipulator, having maximum handling capacity of 250 kg. Specimens with dimension 300 × 150 mm were fabricated. In order to reduce the test program, one specimen was used for welding three welds with different welding parameters. Welding experiments were conducted with two different materials: aluminium alloy AlMg3h22/32 and stainless steel X2CrNiMo17-12-2. The thickness of the materials was in the range of 1.5–4.0 mm. Three different welds were performed (T-joint, outward corner joint, butt joint). Solid welding wires of diameter 1.0 mm, grades G19123L for stainless steel, and Alumig Mg5 for aluminium alloy, were used. Mison 2 mixed gas was used for shielding of stainless steel, and gas mixture Ar/He with the trade name Mison 2He was used for welding of aluminium. Adding helium to argon increases arc temperature and heat input. The materials used in the experiments are shown in Tables 1 and 2.

Experiments were conducted according to information obtained from literature [6,7] and using welding parameters, given in [5]. The fabricated specimens were inspected visually and 17 specimens were chosen for laboratory research. In the visual inspection, throat thickness of fillet welds was estimated. Convexity and asymmetry of welds, presence of spatters and surface pores were assessed. Metallographic analysis was conducted according to standard [8]. Optimal speed of movement of the welding gun has to be found by actual welding experiments. The influence of welding speed on welds dimensions and quality was tested in the range of 7–25 mm/s (0.42–1.5 m/min). In the first experiments backhand welding technique was tested, but due to spatters in the initial stage of welding, forehand welding technique was used. Contact dip to work distance (CDTW) was in the range of 13–15 mm. Welding parameter heat input [kJ/mm] was calculated by the following formula, provided by standard [9]:

$$Q_e = \frac{kUI}{v} \times 10^{-3},$$

where U is arc voltage (V), I is current (A), v is welding speed (mm/s) and k is thermal efficiency factor for the welding process (was used $k = 0.8$). For stainless steel, calculated value of heat input Q_e was in the range of 0.07–0.11 kJ/mm, for aluminium in the range of 0.06–0.18 kJ/mm.

Table 1. Composition and properties of parent materials and welding consumables [10–12]

Grade/tradename	Typical chemical composition, wt%				
X2CrNiMo17-12-2 (AISI 316L)	C	Cr	Ni	Mo	
	0.02	17.3	12.6	2.6	
AlMg3	Si	Fe	Cu	Mn	Mg
	0.4	0.4	0.1	0.5	2.6–3.6

Table 2. Composition of welding consumables [13]

Grade/tradename	Composition, at%			
	Ar	CO_2	NO	He
MISON® 2	97.97	2	0.03	
MISON® 2H	67.97	2	0.03	30

3. RESULTS AND DISCUSSION

Visual inspection showed a high convexity of corner and butt welds. According to the weld quality standard ISO 5817, welded joints may be classified by reinforcement as welds in level C or D [8]. Stainless steel T- and butt joints were successfully produced without welding spatters (Fig. 2). In some specimens partially penetrated welds were observed. T-joints had equal weld legs and at higher welding speeds surface pores were observed. In macrostructures of welded stainless steel joints many small pores near the area of the weld root were observed. When high welding speeds were used ($v > 12$ mm/s), lack of fusion together with high porosity was observed. Due the colder arc and welding pool the absorbed gases are not able to escape during solidification, leading to excessive porosity. Porosity of welds may be decreased by increasing shielding gas flow or by using additional gas supply behind the welding gun. In T-joint, gas cavity near the weld root was observed (Fig. 3b). Welded aluminium joints

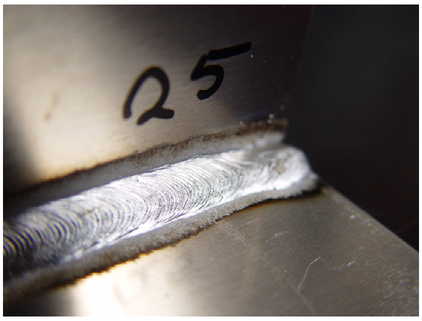

Fig. 2. T-joint, fabricated with welding speed of 12 mm/s; $U = 14.1$ V, $I = 143$ A.

(a) (b)

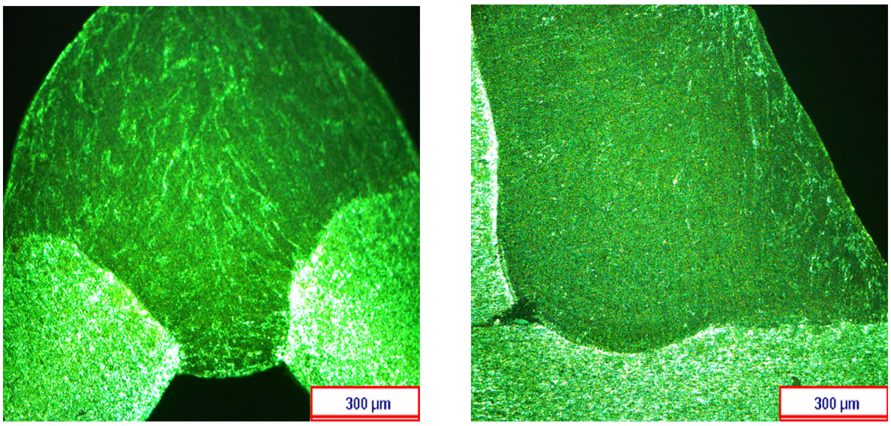

Fig. 3. Micrographs of the cross-sections of welds: (a) corner joint $Q(H) = 0.081$ kJ/mm; (b) T-joint $Q(H) = 0.107$ kJ/mm.

showed cracks on the central line of butt welds. These cracks may be classified as solidification cracks. This phenomenon is usually associated with insufficient weld bead size or inappropriate shape, welding under excessive restraint or sometimes with material properties – such as high impurity content or a relatively large shrinkage on solidification. In the current case the reason for these cracks could be the incorrect choice of the width–depth relationship or the inappropriately selected filler metal for the CMT process.

The results of welding tests are presented in Fig. 3. The results obtained with welding of stainless steel were satisfactory. Data obtained from the experiments can be successfully used for welding other similar products.

4. CONCLUSIONS

Stainless steel spatter free joints of satisfactory quality can be obtained with the robotized CMT process.

Heat input *Q* directly influences the distortions and deformations of welded parts and in case of thin sheet metal the optimal heat input is essential to guarantee the joint penetration with minimum heat input. Welding the stainless steel with thickness of 2–4 mm, the heat input was in the range of 0.07–0.11 kJ/mm. For Al alloys, further studies are to be conducted to determine the heat input parameters. The results obtained in this study correlate with the results obtained in [7], where the CMT technology was adopted for welding of dissimilar metals – Al-alloy with zinc-coated steel. Excessive concavity was noted, also its dependence on the welding speed and current.

The CMT process proves to be suitable for welding of thin sheet metal without spatters. It is essential to determine the right welding speed (speed range) to guarantee low porosity and to minimize distortions in the product. Using the abovementioned welding method and welding speed in the range of 10–12 mm/s for welding of stainless steel proved to be the most appropriate. Further increase of the welding speed will cause excessive porosity but reduces the concavity of the welded joint. This is the actual limit for further increase of productivity by increasing welding speed.

The experiments, conducted with the CMT process in combination with robotic welding, prove that this method can be adopted successfully for manufacturing stainless steel and Al sheet metal products. The general process windows were determined but further experiments with specific joint types are to be conducted for specification and optimization of welding parameters.

Positive results by implementation of the CMT process may be transferred to other companies with similar product portfolios.

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Õhukesest lehtmetallist toodete keevitus CMT-protsessi abil

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Konstruktsiooniteraste keevitamiseks kasutatakse enamasti poolautomaatset MIG-/MAG-keevitustehnoloogiat. Alumiiniumsulamite ja roostevabade teraste keevitamiseks on enim levinud TIG-keevitusprotsess. Antud töö keskendub alumiiniumsulamist ja roostevabast terasest lehtmetalli keevitamisele, kasutades

uudset CMT- (Cold Metal Transfer) keevitusprotsessi. CMT-keevitusprotsess on alternatiiv TIG-protsessile ja selle eeliseks on deformatsioonide vähendamine ning suurem tootlikkus. Põhjuseks on protsessi vähene soojussisestus, mis saavutatakse tänu elektroodtraadi kontrollitud liikumisele. Mõistmaks CMT eeliseid, on antud protsessi optimeerimine väga oluline.

Antud töö eesmärgiks oli CMT-keevitusprotsessi optimeerimine, kasutades olemasolevat robotkeevituskompleksi (robot, manipulaator jne), ja valideerimine. Tootlikkuse tõstmisel on limiteerivaks faktoriks kvaliteedi langus (poorsuse kasv, deformatsioonid ja ebasobiv keevisõmbluse geomeetria).