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Robotic Arc Surfacing in the Additive Technique-Aided Creation of Models

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Abstract: Previously used reconditioning of worn machinery parts based on welding methods, primarily arc surfacing and thermal spraying, enabled the restoring of nominal shapes and dimensions as well as other parameters and functional properties of elements. Intensively developing 3D print additive methods enable the creation of models and functional prototypes, including machinery elements. The article presents original works aimed at the implementation of MIG/MAG robotic arc surfacing (in its low-energy CMT variant) in the design and fabrication of 3D metal models.

Keywords: additive technique; 3D printing; arc surfacing; rapid prototyping

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Introduction

Over the past few months, the research association JOINT has focused primarily on the possibility of creating metal models using robotic MIG/MAG arc surfacing processes. At present, mainly because of the enormous commercial success of 3D printers, additive techniques are enjoying significant popularity. However, a considerable disadvantage of 3D printers is the building material used by them, limiting the mass scale application of the printers to marketing-related purposes. The creation of 3D models through surfacing enables the obtainment of very good properties, similar to those of the base material, and significant freedom as regards shapes of finished elements. Through its use when repairing machinery elements and/or their surface, the process of surfacing is considerably well known.

Additive Techniques

Classification

Additive techniques include methods which enable the shaping of products through applying layers of a building material. The primary division of additive techniques is as follows [3]:

- rapid modelling, used when:
  - preparing educational aids,
  - making mock-ups,

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  - performing marketing analyses,
- rapid prototyping, applied in:
  - functionality tests,
  - mechanical analyses,
  - assembly tests,
  - research,
- rapid manufacturing, used in:
  - piece and low-volume production,
  - production of single non-standard or replacement elements,
  - medicine.

Characteristics of Additive Techniques

The above-presented division is based primarily on functionality criteria, including the precise making of models. **Rapid modelling** is characterised by the lowest quality of elements. Therefore, obtained results are usually used for marketing purposes, e.g. as mock-ups. **Rapid prototyping**, i.e. creating an element being a prototype, thus having the functionality of a finished product, is characterised by higher accuracy. Despite the foregoing, rapid prototyping is used when making elements **imitating**, and not replacing, elements obtained using other technologies. Only **rapid manufacturing** enables the obtainment of full-value elements to be used in actual mechanisms. However, because of high process-related costs, the method does not enjoy significant popularity. Presently, it is estimated that the profitability of production based on additive techniques requires series of between ten and twenty items. After exceeding the above named range, production based on more conventional manufacturing techniques (e.g. casting or machining) proves a more profitable solution. Increasingly often applied additive techniques are still primarily used in the research industry, yet it does not mean that they would not prove successful in lot production. On the contrary, additive techniques have enormous potential, for instance in terms of the possibility of creating complicated shapes. [3]

Arc Surfacing as a Rapid Prototyping Method

Arc surfacing consists in applying a weld deposit on metal surfaces; the weld deposit being obtained from a consumable electrode and mixed with the partially melted surface layer of the base material. The metallurgical bonding of the layer applied through surfacing with the layer subjected to surfacing enables the obtainment of high operational properties. Surfacing-based 3D printing is still a rare solution [4]. Although this process has been a subject of many a research work, only the past few years have seen a growing interest in this method. In addition to its innovative nature, the method is also characterised by **low equipment and material-related costs**. It is well-known that machining entails massive material losses in the form of chips. The surfacing-based creation of 3D models only requires finishing. In addition, in many cases, particularly if the shape of a given element is complicated, it is not possible to obtain a desired effect through machining. The foregoing is a potentially significant advantage of 3d surfacing as it enables the obtainment of elements of complex shapes and characterised by properties similar to those offered by the base material. Another advantage of 3D surfacing is its **high susceptibility to automation**. Welding robots, even if not sufficiently common in Poland, are gradually becoming necessary for the efficient operation of production plants. Another good point, resulting from intense technological progress, is **access to off-line programming systems**, making it possible to develop and simulate an entire programme using a computer before uploading it to a related robotic station (Fig. 1). [1]

CMT in Use

The tests performed by the research association involved the use of the low-energy variety of the MIG/MAG method referred to as the CMT (i.e. Cold Metal Transfer) and developed by the Fronius company. **The characteristic feature of**

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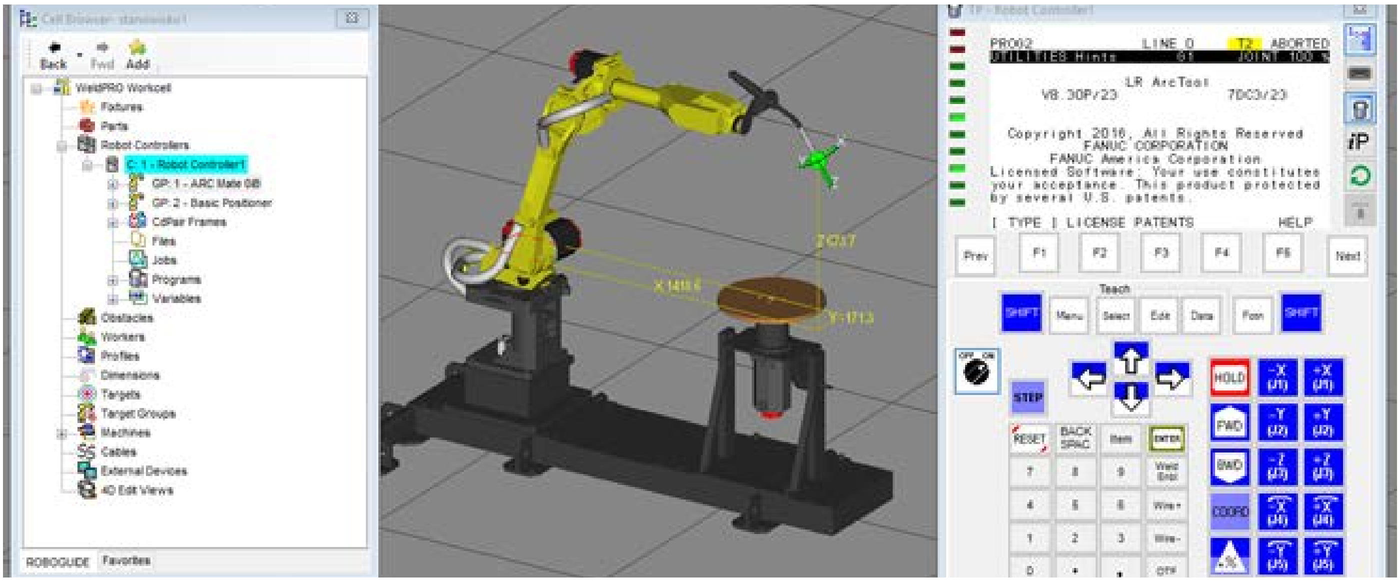

Fig. 1. Off-line programming in the ROBOGUIDE Fanuc environment (individual study)

the method is the manner of filler metal application, where, instead of a standard, i.e. constant filler metal feeding rate, the forward and backward movement of the filler metal is subjected to advanced control. In comparison with standard MIG/MAG, the CMT method is characterised by a lower heat input to the joint (weld) as well as very high process stability and repeatability. The foregoing advantages are of great importance as the applying of successive layers entails the risk of molten metal "downflow". Importantly, CMT makes it even possible to create models having **walls of thicknesses below 3 mm**. The image below (Fig. 2) presents the test involving the flexible adjustment of surfacing parameters aimed to control the thickness of a surfaced wall. As can be seen, it is possible to obtain desired results of the future 3D model in a simple manner. The thickness of the wall on the right amounts to a little more than 2 mm.

In spite of unquestionable advantages, the making of models also faces problems typical of welding/surfacing processes. Primarily, it is necessary to allow for the following issues:

- growing heat input to the model along with each successively applied layer,
- maintaining of the linear build-up of layers requires previous and detailed knowledge of process characteristics,
- conventional MIG/MAG arc surfacing methods enable the making of massive thick-walled models only,
- because of low accuracy and significant irregularity of wall surfaces, models usually need to be subjected to finishing treatment,
- necessity of controlling both the robot and the welding power source impedes the automatic conversion of a CAD-based design to a programme stored in the robot memory.

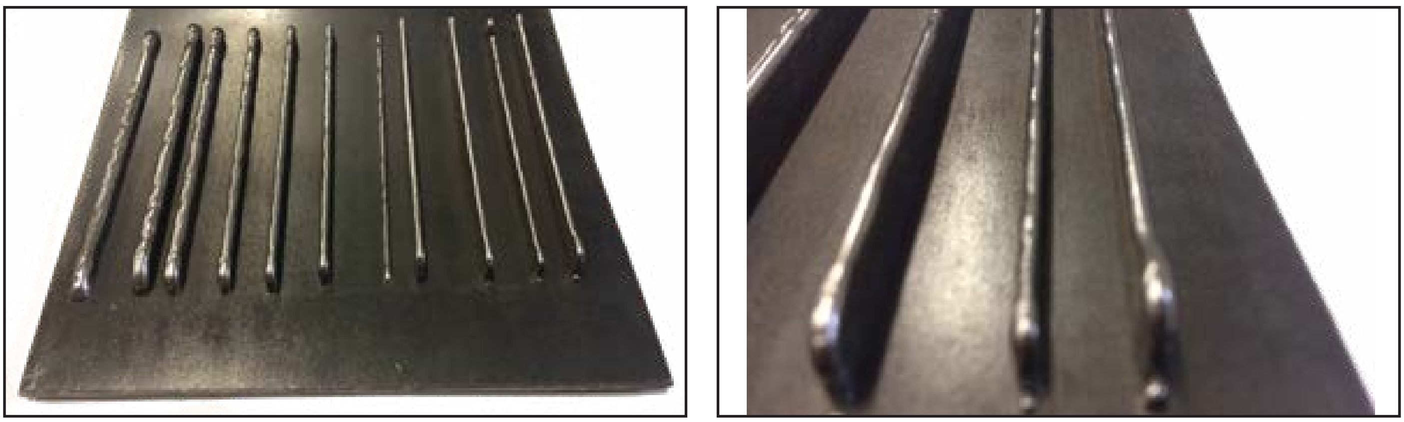

Fig. 2. Various thicknesses of surfaced walls [individual study]

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Obtained Models

Beginnings

Experiments performed by the research association started with the attempted robotic creation of single vertically growing walls. The stage involved becoming familiar with the arc surfacing technique and the programming of a welding robot (IRp-6) as well as solving numerous related problems. Initially, tests involved surfacing based on conventional MIG/MAG methods (pulsed arc and short-circuit arc), yet soon the use of the CMT method revealed its significantly higher process-related quality.

The first body to be crated was a "box". As can be seen in the photograph (Fig. 3), sometimes the process got out of control. The stage was primarily used to determine favourable surfacing process parameters, later used as the basis enabling the creation of significantly more complex bodies.

"Hub"

The first satisfactory result of the research association's work, demonstrating increasingly greater understating of the effect of surfacing parameters and robot movement on the final result, was a "hub" (Fig. 4). **The "hub project" was the first successful attempt to create an element having utility value.**

The first stage involved the mastering of the creation of a cylinder having a diameter of approximately 30 mm. **The creation of objects with circular interpolation revealed a previously unnoticed problem, i.e. the inaccurate positioning of the welding robot**. The solution involved the use of a programmed rotation of the positioner table combined with the robot, lifting the electrode torch (flat position) along with successive layers. An accompanying issue involved the heating of the model along with successive layers. It was necessary to apply cooling between accruing layers. The process as stopped after each three layers, the element was cooled to reach an appropriate temperature and the cycle was restarted. The above-named approach made it possible to control the desired shape of the element.

The second stage involved the making of a flange. According to the previously adopted plan, the flange was to be located at a height of 25 mm, whereas its diameter was to reach 55 mm. **The proper application of the thin-walled flange layers required the flat position of the surfacing process and the horizontal position of the positioner axis of rotation. because of the robot range-related limitations, the position of the table was not changed and the surfacing process was performed in the least favourable horizontal position with the horizontal movement of the electrode along with successive layers.** The previously adopted parameters enabled the obtainment of high dimensional repeatability of the model

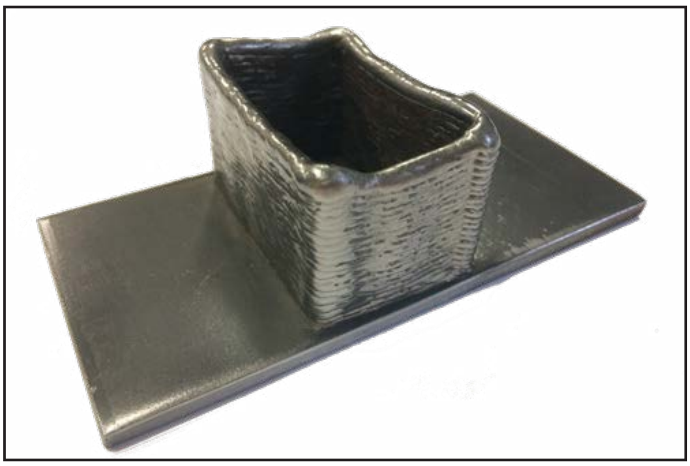

Fig. 3. "Box" made using the arc surfacing process [individual study]

Fig. 4. "Hub" [individual study]

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Fig. 5. "Vase" [individual study]

Fig. 6. Glass [individual study]

(± 0.5 mm). After the completion of the surfacing process, the hub was subjected to finishing using a lathe [2].

Latest Projects

The recent period of the association's activity involved the continuation of experience gained when making the hub. Primarily, it was possible to obtain significantly higher elements (exceeding 400 mm). In addition, the activity also involved the creation of elements using stainless wire ER308, which was initially highly problematic because of the significant instability of the surfacing process. Each change in surfacing parameters or electrode position produced different results. **It should be noted that the finished elements retained the structure and mechanical properties of the base material.**

Subsequent bodies were "vases" of a variable diameter (Fig. 5). It appears that the **making of such an element using conventional method, e.g. through removal machining, could pose a significant problem. The use of surfacing excluded the necessity of making any moulds, templates and welding-related elements in steel**.

The subsequent image presents the "glass" (Fig. 6), preceded by viability tests concerning the possibility and parameters related to the making of a thin ("glass") stem, i.e. the application of subsequent layers related to the minimum cross-section. The final effect was a stem (having a dimeter of approximately 6 mm and located on a conical base) on which a conical vessel was built up.

Summary

Initial attempts at the 3D printing of simple elements made it possible to get to know properties and limitations of selected processes, materials and equipment as well as acquire knowledge, skills and competence necessary for further research. The foregoing resulted in the development of larger designs characterised by more complex geometry.

The apt adjustment and correction, if necessary, of required parameters resulted in the creation of models having functional potential. The recent designs have proved it is possible to create nearly any thin-walled (multilayer, yet single run) body of revolution provided that there are no range and orientation-related limitations of the previously operated five-axial robot. **The previously performed research works justify the conclusion that dimensions of thin-walled models to a greater extent depend on**

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the range of a robot arm than on a technology itself. The recent achievements are primarily based on advantages of the CMT method enabling the controlled and stable pile-up of molten metal without compromising the constant wall thickness.

The potential of 3D printing through arc surfacing is enormous and already arousing great interest in the aviation and shipbuilding industries. Another advantage is the fact that the creation of models requires a relatively short time. Further research performed by the JOINT (research association) will focus on applications of new materials (including aluminium or magnesium alloys) and creation of spatial non-rotation models.

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