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Particularities of an Incremental Forming Application in Multi-layer Construction Elements

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The technologies for low quantity production of sheet metal components and parts have expanded greatly in recent years. They are applied mostly for thin single metal sheets. However, such technologies could also be interesting to form individual multi-layer construction elements. As such construction elements consists of metal plates that are usually hot zinced and painted before forming process, it is necessary to select an appropriate technology with stable process parameters to avoid any damages.

In this article, particularities of an incremental forming application as additional technology in multi-layer construction element production are presented. Special attention is dedicated to the forming principles, the forming influences on the mechanical properties of the multi layer element and the corrosion of the locally deformed coloured metal plate. The latter two activities represent the most important requirements in order to fulfil construction standards and due dates, both independently of unpredictable sharp weather conditions. It was discovered that the statics of the multi-layer element improves if appropriate shape parameters in connection with process parameters are applied, where the painted layer remains undamaged, even after demanding anticorrosion tests.

Keywords: incremental forming, multilayer constructions elements, statics, anticorrosion

0 INTRODUCTION

The technologies for low quantity production of sheet metal components have expanded greatly in recent years. One of those, currently the most attractive, is an incremental sheet metal forming technology where only simple rod-shaped forming tool is used to produce a complex asymmetrical product in low quantities or prototype production [1]. It is applied mostly to form thin single metal sheets, but such technology could also be applied for individual high volume multi-layer construction element production. Such an element is composed of thin metal sheet layers on both sides and some filling material in between (Fig. 1). Glued together, it is a lightweight, self bearing and insulating building block.

The insulation is not the only property of the filling. It makes the outer layers capable of taking compressive strength by providing a firm core structure and thus prevents corrugation and wrinkling. Usually, such structure elements have to withstand unpredictable and severe weather conditions all over the world where strong wind, extreme temperature deviations during the day, humidity and salinity cause significant stress.

Therefore, the characteristic of the incremental technology should be defined so that the formed construction elements would still preserve or even improve their basic functionalities. Thus, they have correspond to construction load capacity standards, which are defined with a four-point standardized bending test and anticorrosion standards in a standardized salt and humid chamber. Furthermore, the integrity of multi-layer elements should be maintained and regions near joints of the elements have to remain un-deformed since they are directly connected with other construction elements.

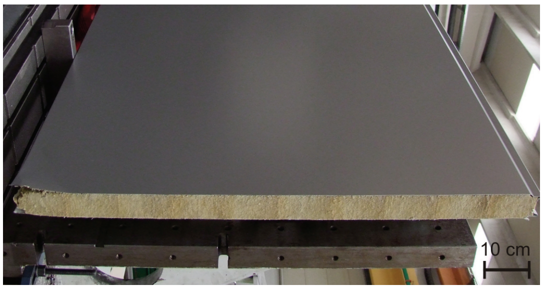

Fig. 1. *Multi-layer element*

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Due to the dimensions of construction elements, which can be up to twelve meters long and over one meter wide, corresponding large-scale technological equipment should be used. Moreover, to be cost-effective, high forming speeds are required, but damaging the construction elements due to high speeds must be avoided. At the same time, classic clamping tools are not sufficient to prevent sheet metal bending in the vicinity of the forming zone.

From the stated reasons, the aim of this article is to present the particularities of the incremental forming application as additional technology in multi-layer construction element production, with regard to the statics of the multi-layer element and corrosion of the locally deformed hot zinced and painted metal plate.

1 PROCESS DESCRIPTION

Extensive development in incremental forming (IF) techniques as well as the rapid evolution of computer-controlled machining in recent years enables the forming of complex asymmetric sheet metal parts. Furthermore, it provides opportunities to form not only numerous different types of materials but also their combinations as multi-layer construction elements.

The incremental multi-layer forming (IMLF) procedure (Fig. 2) is performed with a rod-shaped forming tool with a smooth hemispherical head, which is clamped into the spindle of the forming machine. The multi-layer element is positioned and clamped with a special clamping system on the worktable of the forming machine. The forming tool follows the predetermined tool path and gradually presses and locally forms the upper sheet metal directly under the tool head with a very small value of deformation until the final geometry of the product is reached.

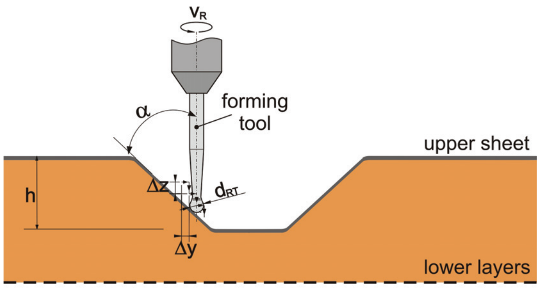

Fig. 2. *Principle of IF in multi-layer elements*

2 FORMING PARTICULARITIES IN MULTI-LAYER ELEMENTS

The experimental work concerning this investigation was carried out on CNC-controlled milling machine – SECMU. The machine working area is 3000 x 1700 x 1300 mm.

The basic technological parameters needed to perform the experimental test are presented in Fig. 2 (i.e. α [°] - wall angle, v_R [rpm] – tool rotation speed, d_{RT} [mm] - tool diameter, Δz [mm] - vertical step size, Δy [mm] - horizontal step size and f_{RT} [mm/min] - feed rate). They were determined on the basis of preliminary research of incremental forming of single sheet metals [2] to [4] as well as multi-layer construction elements. It is worth pointing out that the motion of the forming tool depends on test conditions and the shape of the particular work piece. The tool path includes the movement in 3D space, as well as synchronized rotation along the z-axis.

Multi-layer construction elements consist of outer and inner cold-rolled hot-zinced and painted steel sheets of 0.6 mm in thickness and a barrier layer between them. They are fixed on the machine via the inner layer, so the other layer to be formed remains free.

In order to avoid any undesired issues arising from friction between the forming tool and the work piece, a special lubricant was used.

2.1 Determination of the Forming Forces at IF of Multi-layer Construction Element

In general, the accurate prediction of the reaction force during forming processes is very important, especially with regards to selecting appropriate equipment (e.g. forming tool, machine, clamping system, etc.) and optimal process parameters. With the incremental forming of multi-layer construction elements, the prediction of forming process using commonly applied tools such as the finite element method, last square method, various analytical approaches, etc. is very difficult due to the proper description of the material properties of the non-metallic core of multi-layer element. Fortunately, in most cases the barrier layer does not have a fundamental contribution to the levels of forming forces. The reason is localized IF load, which contributes to local compression failure of the barrier layer.

Therefore, the reaction force in z-direction, which is the most critical during incremental forming, were calculated approximately according to the analytical model of single point incremental sheet metal forming proposed by Petek [2]:

$$F_z^i = \frac{2}{\sqrt{3}} \cdot \sigma_f^i \cdot A^i \cdot \sin\alpha^i \qquad i = 1 \ldots n, \tag{1}$$

in which the parameters are: F_z [N] - forming force in z-direction, σ_f [N/mm^2] - the equivalent stress, A [mm^2] - section on which σ acting, α [°] - wall angle and n - number of forming steps.

It was discovered that the application of incremental technology in multi-layer construction elements would not cause problems for the selected CNC machine whose limited load is 50 kN, since the forming force (F_Z) of cold-rolled, hot-zinced and pre-painted steel sheets of 0.6 mm in thickness is approximately 1 kN.

2.2 Forming Influence on Static Behaviour of a Multi-layer Element

On a flat surface of the work piece, four-point bending tests were carried out after the forming procedure according to standard EN 14509:2006 (Fig. 3) in order to investigate the properties of the multi-layer element [5]. The large span of four meters is used to ensure a bending failure (wrinkling or face buckling). The force (F) and deflection (w) were measured during the test. After a failure, detailed examinations of the interesting regions were performed. It includes the integrity of the whole structure, bonding between the face and the core as well as their individual properties.

The results show some interesting features. First, there is significant influence of forming design to the load capacity of the multi-layer element, which can be decreased but also highly increased.

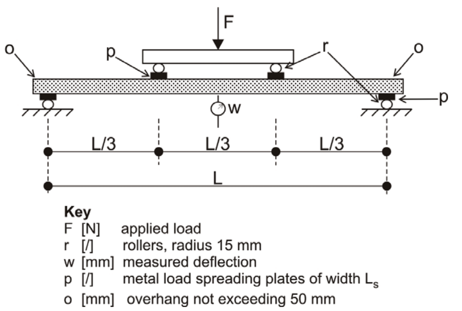

Fig. 3. *Four-point bending test (EN 14509:2006)*

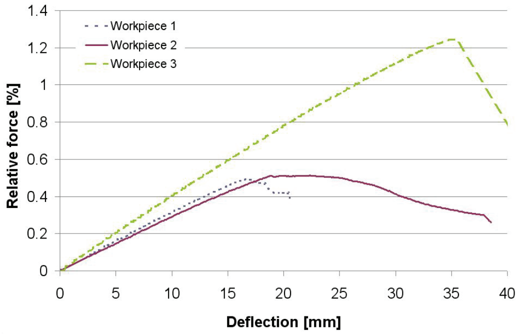

Fig. 4. *Relative force according to the nominal values of basic element during bending tests*

Figure 4 shows the relative bending capacity of the element according to the nominal capacity of the un-formed element in a standard bending test. Two extreme cases are presented: work piece 1 and 2 with the worst case design and work piece 3 with good design. The results show that a change between -40% to +30% can be expected. The failure zone of the work pieces after the tests is presented in Figure 5. The last can be achieved by smart designs preferring longitudinal curve directions, not too small curvatures at crossing, fading in/out types of start/end points and balanced depth of forming. Second, relatively major local deformation under formed paths results in local compression failure of the core.

The width of this phenomenon is approximately two to three times the tool diameter, so the minimum distance between the paths can be calculated so that at least two thirds of the element width remains untouched. Incremental forming without a special clamping system driven with the forming tool leaves some compressive/tensile stresses in the surface material, larger for shorter paths; special care should be dedicated to the design in order to avoid such an accumulation.

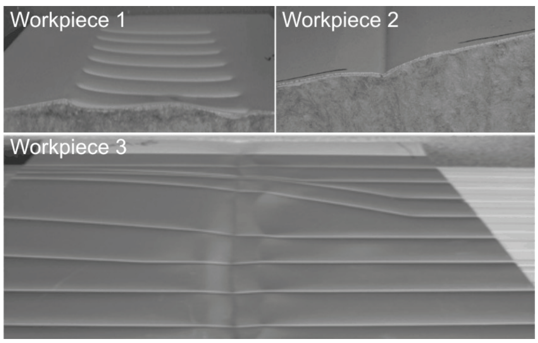

Fig. 5. *The failure zones after the static tests*

2.3 Anticorrosion Characteristics and Tests

To perform forming operations on the final product without additional protection or surface treatment stabile and highly controlled process is required. Therefore, several types of tests were performed in order to examine if incremental technology corresponds to a standards in this field.

The work pieces have been cut by segments of 100 x 200 mm of deformed surface layer (Fig. 6-left). Four design patterns was used, each of many combination of forming depth and width, tool radius, different colour types and colours (PS/PUR/PVDF), zinc and base material thicknesses as well as suppliers. Over 280 specimens were tested according to test procedures, mentioned in Table 1.

Table 1. *Anticorrosion test procedures*

Type	Standard	Requirement [hour]	Performed inspection [hour]
Humidity chamber	EN 6270 – 2:2005	min. 1000	after 340, 500, 1000
Salt chamber	EN 9227:2006	min. 500	after 340, 500, 1000
Tropic box	company reference	min. 360	1056

Testing procedures have been made according to bubbling (EN 4628-2:2004, Fig. 6-right), corrosion (EN 4628-3:2004) and peeling (EN 4628-8:2005).

Results show that majority of specimens exceed requirements and that the formed area can be treated in the same way as the rest of the surface. As no special limitation has been set, many options are possible.

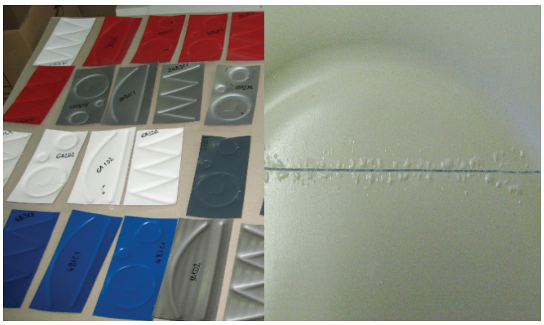

Fig. 6. *Work pieces for corrosion test (left) and result of a bubbling near a cut (right)*

3 CONCLUSIONS

Completely individual designs of the multi-layer construction elements can be applied due to the modern technological approach called incremental forming. A novel application of this technology is presented. Supported by analytical models and simulations, several practical tests confirmed that forming can be achieved without undesired effects, thus opening a wide spectrum of possibilities.

Special requirements for multi-layer construction elements are recognized also by the organization CEN as a new potential market segment. In order to make a formal regulation, a new standard is being prepared (TC128 SC11 WG1), which will hopefully also cover the IF technology presented here.

Finally, it can be concluded that proper design and process parameters can preserve or even improve all technical characteristics of the basic multi-layer element, thus conforming to high quality standards.

4 ACKNOWLEDGEMENTS

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