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Welding of non-nominal geometries – physical tests

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Abstract

The geometrical quality of a welded assembly is to some extent depending part positions before welding. Here, a design of experiment is set up in order to investigate this relation using physical tests in a controlled environment. Based on the experimental results it can be concluded that the influence of part position before welding is significant for geometrical deviation after welding. Furthermore, a working procedure for a completely virtual geometry assurance process for welded assemblies is outlined. In this process, part variations, assembly fixture variations and welding induced variations are important inputs when predicting the capability of the final assembly.

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1. Introduction

In aerospace industry, sustainability requirements are drivers of lightweight solutions. As a result of this, large casted parts are being replaced with smaller parts in lighter material that are welded together. This strategy is sometimes referred to as “fabrication”. Weight is saved, but other problems related to tolerances and geometrical variation arise. The parts themselves are non-nominal due to previous manufacturing processes and the assembly fixtures might also vary due to wear. Furthermore, the welding process itself adds variation. Those sources of variation might lead to products not fulfilling customer requirements or costly and time consuming rework operations.

To compensate for fixture or part disturbances, the parts to be welded are often clamped to nominal position close to the weld path. However, this introduces stresses in the parts and the effects from this are not fully understood. In this work, the effect from clamping is investigated using physical tests. The focus is on geometrical deviations after welding, so effects from the introduced stress on life, strength etc are not considered.

Earlier, this kind of investigations have been done based on simulations [1, 2]. However, no physical verifications were done. Furthermore, in this paper the effects from symmetry in part disturbances are investigated.

In Section 2, an overview of geometry assurance is given. In Section 3 the case study is presented, followed by the results from the case study in Section 4. In Section 5, some guidelines for geometry assurance of welded assemblies are presented. Conclusions can be found in Section 6.

2. Geometry assurance

Geometry assurance is a concept used to gather activities and tools used to minimize the effect of geometrical variation in parts and in the assembly process with respect to geometrical quality of the final product. Low geometrical quality of the final product means large geometrical variation of the product, often leading to severe effects on both functional and esthetical requirements. Geometry assurance is a natural part of the product development cycle in automotive industry, but is in many cases not completely adapted within aerospace industry. With larger series, fabrication strategy and

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increased competition, a process for geometry assurance is sought after also in aerospace industry.

The geometry assurance process starts with finding robust design concepts, insensitive to variation. Different concepts can be compared and evaluated. Locating schemes, which describe how the parts are positioned during assembly, control the variation propagation from part level to assembly level and are critical during this stage of the geometry assurance process. A rigid part has six degrees of freedom (three rotations and three translations) that must be locked by the locating scheme. For a non-rigid part, additional support points can be added to the original six locating points to avoid deformation of the part due to gravity and other forces. The locating points are physically realized by the contact between the fixture and the part, i.e. the locators. More about locating schemes can be found in [3].

Geometry assurance activities are also present in the verification phase, where the product and the production system are physically tested and verified. In this phase also inspection preparation and off-line programming of coordinate measurement machines and scanning equipment takes place. Here, all inspection strategies and inspection routines are decided.

In the production phase all production process adjustments are completed and the product is in full production. Focus in this phase is on inspection data to control production and to detect and correct increased deviation and/or variation [4]. There is a cost for inspection, but this cost should be compared to the cost for non-detected quality issues [5].

Among the tools in the geometry assurance toolbox, variation simulation is perhaps the most important one. This kind of simulation takes part variation, assembly fixture variation and assembly process variation into account and predicts the geometrical outcome of the final assembly. By using such a tool iteratively, tolerances can be chosen in such a way that the requirements on assembly level are fulfilled.

A lot of work has been done in the area of variation simulation for non-rigid sheet metal parts, joined by spot welding or riveting [6-9]. For spot welding, the effect from heat is assumed to be minor and not included in the simulation. Often, variation simulation is based on the Monte Carlo (MC) method, where thousands of iterations are run in order to create statistical distributions for the deviation in a number of critical dimensions on the final assembly. In order to reduce the simulation time for non-rigid variation simulation, the method of influence of coefficient (MIC) is used [10]. The MIC means that a linear relationship between part deviations and assembly spring-back deviations is used in the simulations to avoid new finite element analysis (FEA) calculations in each MC iteration.

Considering assemblies joined by continuous welding, not that much work has been done in the area of variation simulation. The welding process give rise to heat that deforms the parts, changes in the mechanical properties and the micro structure and may also introduce, or release, residual stresses.

Deformation due to welding is difficult to include in variation simulation in an efficient way, since the simulation of the welding process normally is very time consuming and not possible to linearize, so the MIC method cannot be applied. Welding simulations are therefore usually done on nominal models.

However, in [1] variation simulation and welding simulation were combined and it was shown that it is not possible to do a variation simulation and a welding simulation separately and superpose the results. The effect from welding must be calculated for each MC iteration.

Lee et al. [11] used a pre-genereated database to include the effects from welding. They did however not consider the coupling between part variation and welding distortion. Lorin et al. [12, 13] have developed a fast and somewhat simplified welding simulation method that can be combined with variation simulation. Madrid et al. [14] present a conceptual framework for variation contributors to fabricated aerospace components.

3. Case description

The purpose of the case study is to investigate:

- If deviations on part level affect the deviation after welding on subassembly level.
- If yes, what this relation looks like.

The case study is consisting of two rectangular parts that are to be welded together, as seen in the sketch in Fig 1 and the photo in Fig 2. A locating scheme with one additional support point is used. The locators A1, A2, A3 and S1 control the part in Y-direction (in/out of the plane) and are physically realized with clamps (marked with X in Fig 1). The locators B1 and B2 control the part in X-direction and the locator C1 in Z-direction. B1/C is physically realized with a pin in the fixture and a round hole in the part (round circle in Fig 1) while B2 is physically realized with a pin/slot contact (oval hole in Fig 1).

The positions of locators A2 for plate 1 and/or plate 2 are disturbed according to the test plan seen in Table 1. Note that some test cases were identical (test 1-3, 8-9 and 11-12 respectively). Those groups are colored grey in Table 1. At this stage, only disturbances in Y-direction were investigated. In future research, different kind of disturbances and combinations thereof might be of interest to analyze.

The variation in the part geometry, i.e. the difference between the different plates used in the experiment, was kept to a minimum by laser cutting the parts.

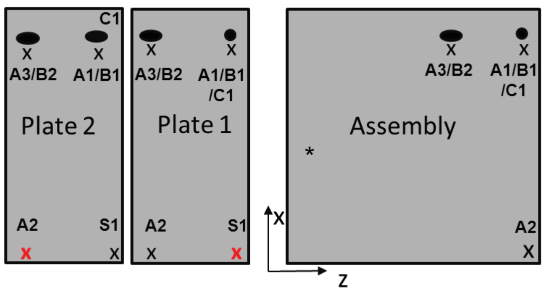

Fig 1: A sketch of the case study.