

APPLICATION OF FIXTURES PRODUCED WITH FDM TECHNOLOGY IN THE ADHESIVE BONDING OF PARTS IN THE RAILROAD INDUSTRY

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Abstract: Additive manufacturing enables the production of parts with complex geometries that would be difficult or impossible to produce with conventional manufacturing technologies - and with minimal waste. A more massive use of additive technologies makes it possible to shorten supply chains and reduce the need to store parts.

Fixtures are essential production aids that position, hold and support workpieces, ensuring positioning accuracy, repeatability and operator safety during assembly and bonding. This paper presents how the Fused Deposition Modeling (FDM) process can provide such fixtures for the adhesive bonding of metal parts in rail vehicle composite structures. By adapting geometry, surface properties and ergonomics to the bonding task at hand, FDM fixtures improve alignment accuracy and simplify handling.

Keywords: FDM; fixtures; adhesive bonding; railroad industry.

1. INTRODUCTION

The railroad industry is experiencing a transition to lightweight composite vehicle structures [1,2] joined with high performance structural adhesives [2]. The increasing use of composites underlines their crucial role in modern engineering practice and the continuous pursuit of innovative design solutions [3,4]. Example of composite tram's cabin is presented at Figure 1.



Fig.1. Tram's cabin preparing for transport after production

Adhesive bonding represents a challenging and rapidly evolving area of research that has already gained significant attention from industry [5-7], and adhesive-bonded joints have become an excellent alternative to conventional joining methods [8]. The expansion of adhesive bonding in industry has been closely associated with the broader application of composite materials and the increasing demand for joining of dissimilar materials [9].

Additive manufacturing enables the production of parts with complex geometries that would be difficult or impossible to produce with conventional manufacturing technologies - and with minimal waste [10,11]. A more massive use of additive technologies makes it possible to shorten supply chains and reduce the need to store parts [11].

Fixtures play a critical role in manufacturing: they accurately position, support and secure the parts to be assembled, and this function can account for up to 29% of the total capital cost of a project [12].

Beyond their basic purpose, fixtures offer a variety of benefits, including the following [13]:

- Increased production: they reduce set-up times and streamline workflows, increasing overall production rates.

- Dimensional accuracy: Accurate control of part location minimizes variation and ensures consistent product quality.
- Lower costs: Faster cycles, fewer rejects and longer tool life reduce manufacturing costs.
- Reliable interchangeability: Precise, repeatable positioning guarantees that the parts fit together exactly in subsequent assemblies.
- Less testing: Consistent accuracy reduces the need for extensive in-process testing and quality control work.
- Reduced skill requirements: Even semi-skilled operators can safely operate the machines, reducing labor costs while maintaining quality.

Research [14] give experimental investigation on the effect of adhesive distribution on strength of bonded joints. High quality bonded joints require the use of equipment (fixture) that is essential for proper curing and uniform thickness. Improper adhesive application and fastening (method of fixturing) can cause irregularities in the distribution of the adhesive along the overlap, which can affect the strength of the joint. This is especially critical for aerospace components, as replacing parts can be costly and time consuming.

Research [15] presents design of hybrid welding jigs with additive manufactured (AM) functional elements for pre-series automotive body shops. In order to select the most suitable AM material, the AM materials with the highest cost-specific stiffness are analysed. The tests prove that the AM elements are stiff enough to withstand the process forces and securely fix the positions of the welded parts.

Günther Schuh et al [16] highlight high potential of Topology optimisation (TO) and Laser Powder Bed Fusion (LPBF) for the manufacturing of welding jigs used in automotive body shops. The results confirm that components optimized by Topology Optimization (TO) and manufactured with Laser Powder Bed Fusion (LPBF) have better physical and structural properties compared to the original designs. These elements not only achieve a significant reduction in volume and mass - between approximately 30% and over 65% - but also show improved performance under mechanical loading. These results highlight the considerable potential of metal additive manufacturing (AM) technologies, especially in combination with TO, for lightweight design in applications exposed to high loads.

Previous studies have clearly shown the importance of fixtures, as they can lead to a significant reduction in production costs. In addition, the use of fixtures leads to an increase in productivity, interchangeability and a reduction in the necessary quality controls. High quality adhesive joints depend largely on fixtures that ensure positioning of the parts, proper distribution and curing of the adhesive and prevent the occurrence of irregularities. Additive manufacturing of fixtures has a wide range of applications, mainly due to the proven mechanical properties of the materials used and the possibility of reducing the weight of the fixture itself. Lightweight fixtures are much easier to handle in production, which confirms the perspective of using additive technologies in the production of fixtures.

This paper presents the application of fixtures produced with FDM technology in the adhesive bonding of parts in the railroad industry.

2. DESIGN OF FIXTURES PRODUCED BY FDM FOR ADHESIVE BONDING

At the outset, it is important to point out that a certain amount of information and photos are censored due to data protection obligations and to protect end customers. Knowledge of the technologies used to manufacture composite structures, their basic phases and limitations is crucial for the design of a fixture for positioning metal parts when bonding them to composite structures. Some of the widely used manufacturing technologies are: open molding, closed molding, infusion (Figure 2), etc. Technologies for the production of composite parts enable the production of not only lightweight but also geometrically complex objects, especially through the use of molds. The molds are elements that are obtained directly from the 3D model and represent its negative. After cleaning, the surface of the mold is coated with gelcoat. The main purpose of this surface coating is to ensure a smooth and shiny surface and protection against UV radiation and water, but also to make the finished product easier to separate from the mold after curing. In the next phase, layers of fiber reinforcements are laid and the resin is applied.



Fig.2. Appearance of the composite after the infusion process

After curing and removal from the mold, the surface of the composite part on the side of the mold is of better quality and serves as a reference for positioning.

The repeatable positioning and alignment of a metal workpiece is achieved by interlocking degrees of freedom (DOF). Rigid bodies generally have six degrees of freedom in space, namely three translational degrees of freedom along the axes of the cartographic coordinate system and three rotational degrees of freedom around the corresponding axes.

The Figure 3 represent part of technical drawing that define adhesive bonding of metal plates (positions 2 and 3) to composite cover (position 1). Visible side (reference) for positioning is also indicated. The starting point for the design of fixtures is the analysis of the visible (reference) surfaces as well as the analysis of the degrees of freedom that need to be locked. By attaching a

metal plate 3 to the back of the composite (Figure 4), one translation (along the W axis) and two rotations (around the U and V axes) were locked. It is necessary to lock three more degrees of freedom, two translations (along the U and V-axis) and one rotation (around the W-axis).

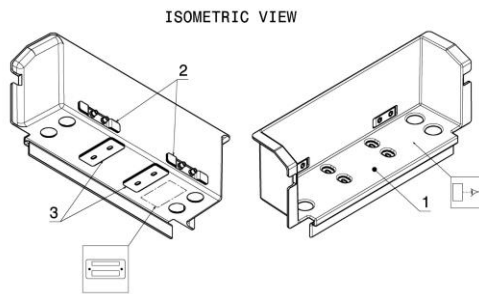


Fig.3. Part of technical drawing

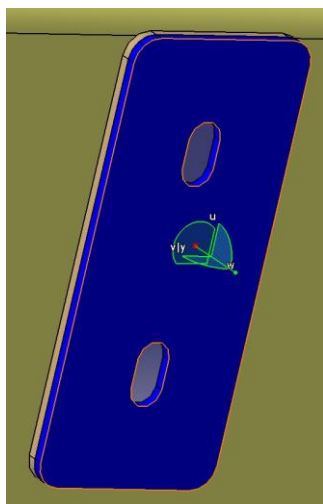


Fig.4. Metal plate attached to the back side of composite part

Figure 5 shows the final appearance of the fixture with the marked features. Feature 1 of the slot-shaped form is sufficient to lock all three required degrees of freedom. Features 2 of the cylindrical shape serve to prevent the rotation of the fixture itself around the W-axis. Surface 3 is the contact surface between the device and the composite.

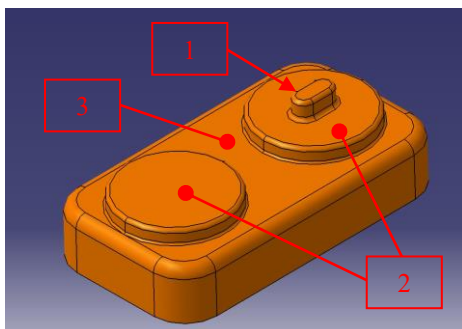


Fig.5. Final appearance of the fixture

The following example (positioning of plate 2) shows a combination of additively manufactured fixture with

standard elements (bolts). Two standard bolts are used for the positioning of plate 3, which are connected to threaded rivets attached to the plate. The reference contact surfaces of the fixture are marked in blue, while the axes of the through-holes are shown in white (Figure 6).

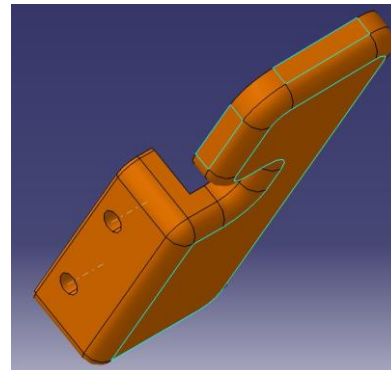


Fig.6. Fixture for positioning plate 2

The final appearance of the fixture with bolts is shown in Figure 7.

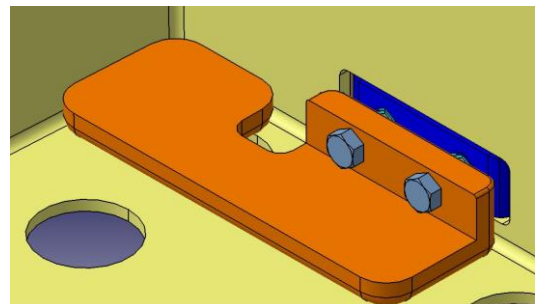


Fig.7. Fixture for positioning plate 2 with standard bolts

The previous examples are relatively simple and serve only to understand the basic design principles of fixtures for adhesive bonding parts and composites. Figure 8 shows a fixture with much more complex geometry used to position headlights for the front fairing of the train. Figure 9 shows fixtures made from sheet metal together with additively manufactured fixtures on a transportation tool in the workshop.



Fig.8. Fixture for positioning headlights for the front fairing of the train



Fig.9. Sheet metal and additively manufactured fixtures

3. CONCLUSION

The article presents examples of the design of fixtures for positioning parts for adhesive bonding in the railroad industry. The design of fixtures requires knowledge of the manufacture of the composites themselves, general knowledge of fixtures and knowledge of the principle of interlocking degrees of freedom. The current state of the art in this field clearly shows the importance of fixtures in mass production and the possibilities of using additive technologies to manufacture these elements. The further development of AM and optimization methods such as topological optimization will certainly lead to an even greater spread of additively manufactured tools in the industry.

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