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AUTOMATED FIBER PLACEMENT SYSTEMS OVERVIEW

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Abstract

This paper presents research results in the field of Automated Fiber Placement (AFP) systems dedicated for composite aerostructures manufacturing. The currently available AFP systems are reviewed with the aim to evaluate importance parameters of this technology. In the scope of this work automatic fiber placement method is presented. Systems with various architectures, from small till industrial application, are described and supported by examples of incorporating that method by aviation industry. Typical materials dedicated for AFP technology are presented. The advantages and limitations of various system configurations in terms of parts size, parts shape and composite materials are discussed. The economic aspect of this technology is also presented with comparison to traditional hand layup technology.
Keywords: composites, aerostructures, fiber placement.

1. INTRODUCTION

Advance aircraft structures such as Boeing 787 and Airbus A350 XWB contain about 50% by weight of composite components. The size of components and required production rate force composite structure producers look for more productive and cost efficient manufacturing methods. A common method being introduced by the largest airframe producers to address cost and production rate requirements is Automated Fiber Placement. During the last decade AFP technology got more popular and affordable, several western aerostructures manufactures have got equipped and successfully incorporated and certified this method for their products. In the following sections AFP method details are presented and importance of R&D work required for successful introduction of this technology into production.

2. AUTOMATED FIBER PLACEMENT TECHNOLOGY OVERVIEW

The most common process for fabrication advance aerostructures is composite prepreg hand layup. Ply definition defined in dedicated design software, like Fibersim or Catia CPD, is transferred to ply cutter. After plies are cut, they are transferred to clean room where an operator locates each ply on the mould tool with the assistance of the laser projection system. An example of hand layup prepreg is shown in figure 1, [1].

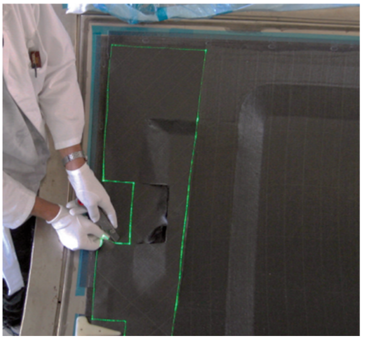

Fig. 1. Basic composite part fabrication with hand layup method [SL-Laser GmbH, 2015]

The advantages of hand layup lie in the fact that this method does not require expensive equipment and an experienced operator can fabricate parts with a complex shape. The main disadvantages are referred to the quality of parts which is dependent on experience of the operator and also the fact that this method is relatively slow. Considering this fact, western airframe producers started to look for a more efficient method. The solution for this need is Automated Fiber Placement technology [2].

The idea of Automatic Fiber Placement technology is to lay composite layer with 0,25” width unidirectional prepreg tape. Each single tape is laid down by a robotic system with butt joint. Each layer can be laid with different orientation, which benefits a structure capable to carry load in the required direction. Each tape is pressed to the mould by a roller for proper compaction.

The general idea of this technology is shown in Figure 2, [2].

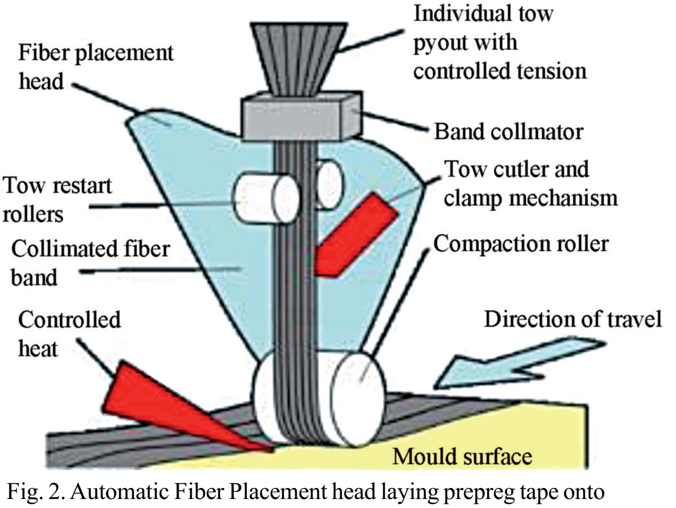

Fig. 2. Automatic Fiber Placement head laying prepreg tape onto the mould [Coriolis Composites, 2015]

3. AUTOMATIC FIBER PLACEMENT SYSTEM ARCHITECTURE

The AFP systems are typically individually suited for a particular application, however, each of those systems has a typical subcomponent. These are:

1. Head with compaction roller;

2. Fiber feeding system;
3. Robotic arm;
4. Control panel.

Typical AFP system subcomponents are shown in Figure 3, [3].

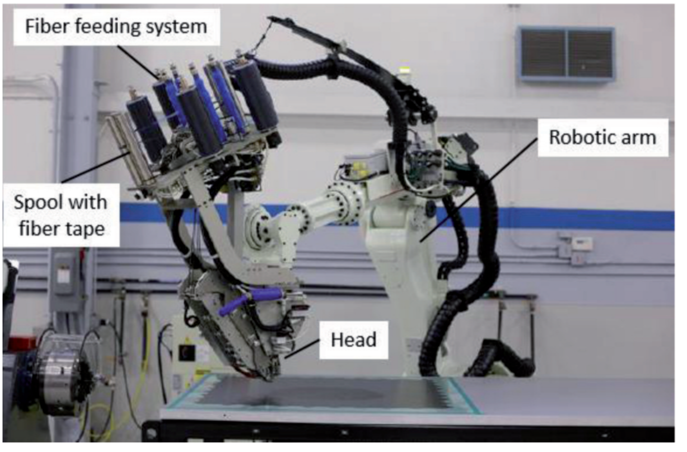

Fig. 3. Automatic Fiber Placement system subcomponents [Automated Dynamics, 2015]

An important part of the whole system is control software. Typically, AFP producers provide a dedicated software together with the system. The software controls the robot motion and technology parameters like: tape laying speed, compaction force, heat source temperature. The software can also analyse fiber direction and perform simulation in order to avoid collision of the robot with a mould tool.

The system presented in Figure 3 is designed for small part manufacturing. The industrial robotic arm is grounded, which limits the robot motion and the maximum parts size. This setup is typically used for R&D work.

In order to reduce the layup time heads are designed to layup several material tapes in parallel. For R&D application typical 1, 4 or 8 tapes head is used, for industry application a head with 16 or 32 tapes is more common.

Considering parts size, AFP head can be mounted on a bigger robotic arm and the robotic arm can be attached to the rail. An example of industrial AFP system with a large robotic arm assembled on the rail is shown in figure 4, [2].

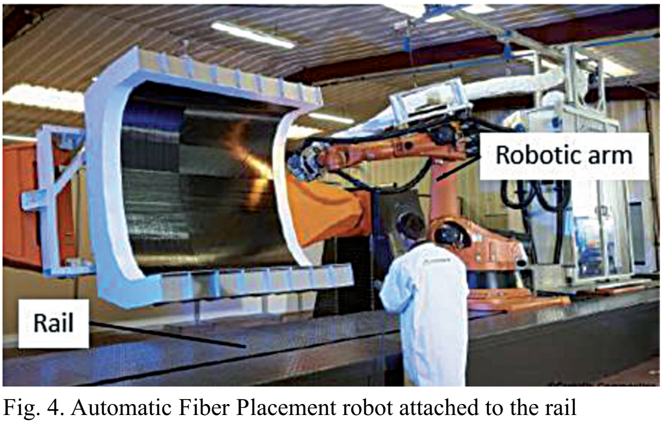

Fig. 4. Automatic Fiber Placement robot attached to the rail [Coriolis Composites, 2015]

A system equipped with a rail benefits with possibility to build long parts. The rail system can also allow to work with a single robot on several different mould tools assembled on positioners or on the ground. An example of a single robot equipped with a rail and 2 mould tool positioners is shown in figure 5, [2].

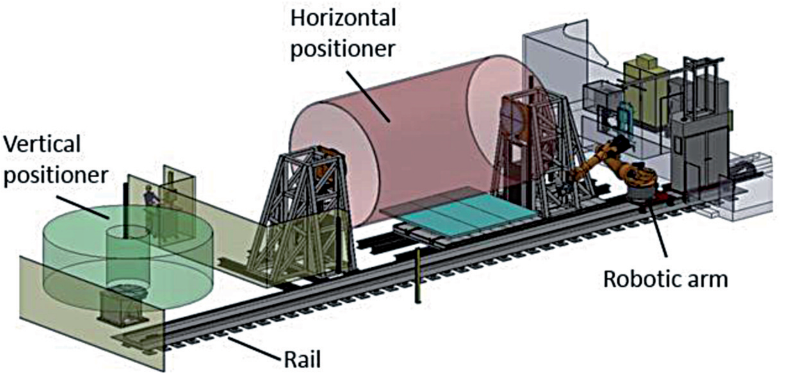

Fig. 5. Automatic Fiber Placement System equipped with rail and 2 mould tool positioners [Coriolis Composites, 2015]

For large part like wing covers or fuselages, gantry style automatic fiber or automatic tape laying systems are used. An example of large parts manufacture with "gantry style" system is shown in figure 6, [4].

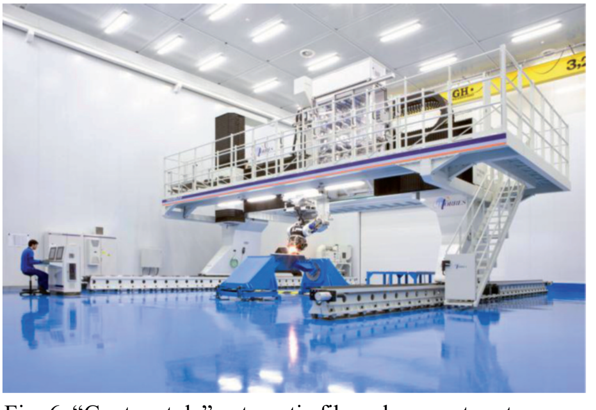

Fig. 6. "Gantry style" automatic fiber placement system [M Torres, 2015]

4. COMPOSITE MATERIALS DEDICATED FOR AFP TECHNOLOGY

Commercially available AFP systems can work with 3 types of composite materials:

1. Thermoset fiber;
2. Thermoplastic fiber;
3. Dry fiber (unsaturated).

Each material is supplied on a standard spool as a unidirectional tape, the most common tape width is 0.25" and 0.5" for large structures [5]. The most common material system used for aerostructure build are thermoset materials, which is also reflected in AFP technology. Each composite material producer offers materials as a tape dedicated for AFP processing. An example of thermoset material is Hexcel 855AS4 tape. After fiber placement process completion a material requires oven or autoclave post processing.

New generation AFP systems are equipped with a laser heat source to allow thermoplastic materials processing.

A combination of AFP system with thermoplastic materials with an aim to achieve in-situ parts fabrication can be very beneficial from the cost stand point. That technology has been used in industry for several years. Nowadays, it can be observed application of in-situ thermoplastic composite technology for aviation industry. Research is still being conducted to obtain a high material quality by means of using in-situ AFP technology with thermoplastic materials [6, 7].

An example of thermoplastic tape is Cytec APC2-34-AS4. Thermoplastic composites have several advantages [7]:
1. Good damage tolerance properties;
2. Superior chemical resistance;
3. Non-limited storage time;
4. Recyclability.

These advantages make thermoplastic composites a very interesting material for aerostructures parts manufacturing, not only from the cost perspective but also from structural strength capability stand point.

AFP system producers also developed processes to support infusion and resin transfer moulding (RTM) fabrication. It is accomplished by placing dry tapes that can stick to the under layer. Laid down dry fiber can be sated with resin by infusion or RTM processing. An example of dry fiber AFP tape is CYCOM 7720 binder coated fabric.

5. AFP TECHNOLOGY ADVANTAGES AND LIMITATION

The main advantages of AFP system are as follows:
1. Producibility;
2. Fiber direction accuracy, [8];
3. Part to part repetability;
4. Low amount of material waste.

Industrial AFP system can be equipped with multi tow heads to increase layup speed. There is no necessity to prepare plies flat patterns like for hand layup, also de-bulking (a process used while composite hand layup to apply vacuum bag every couple of composite layers for better plies nesting and removing unnecessary air contaminated between prepreg plies operations) can be limited or removed from the process. All of that reduces fabrication cost.

AFP system layup of composite tapes is accordant to the defined tape path. In the case when mould geometry enforces tape direction changes, it is known before a part is made. After optimization of AFP program for a particular part, each part is manufactured in the same way and operator to operator variation is eliminated.

Very important advantages of AFP method is a low amount of material waste. Comparing to hand layup where each ply shape is cut from material roller creating larger amount of waste material, AFP system just cuts each tape and restarts it in the area where it is needed.

Automatic fiber placement system has also several disadvantages and limitations. Typical limitations are related to the mould shape. Compaction roller diameter and head geometry limits female mould radiuses that can be used for parts built with this technology. Other disadvantages are related to ply edges created by cut tapes. This is not a problem on part edges which are typically trimmed, however, in local composite build ups sawblade shape ply contour, (figure 7) is a phenomenon that a designer needs to accept [2].

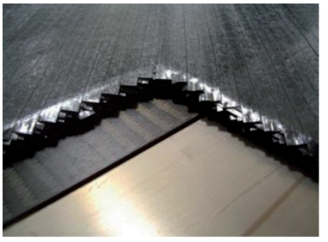

Fig. 7. Ply edge with characteristic sawblade contour obtained by AFP process [Coriolis Composites, 2015]

6. ECONOMIC ASPECT OF AFP TECHNOLOGY

The speed of hand layup is depended on several factors, however, a good average is 1 hour of work to hand layup 1m^2 of prepreg material. Having a fairing with the area of 2 m^2 meters and on average 10 plies, it takes 20 hours to hand layup a single part. That time is driven by ply cut operation performed before hand layup and de-bulking process done while layup operation.

Work can become more difficult when large scale parts need to be built, for example, fuselage (fig. 8), [9] or wing covers. In this situation, either a mould tool needs to be assembled on a movable positioner or an operator needs to work standing on a lifting stand. This will reduce producibility as well.

Fig. 8. Airbus A 350 fuselage panel manufactured with gantry style Electroimpact AFP machine [PF Products Finishing, 2015]

AFP technology can eliminate the issues described above. The system with 8-tow head (0.25”tape), can layup 1 m^2 of prepreg in 3 minutes. That speed can be improved by the system with 16 or 32-tow heads. Compaction roller applying constant pressure on a composite tape assures proper nesting and reduces or eliminates the de-bulking operation. The same fairing with the area of 2 m^2 can be built with 8 tow AFP machine in 1 hour, 20 times faster than using traditional hand layup technique. Assuming average labour cost of 100 € per 1 hour, in that particular case, it can be obtained 1900 € labour cost saving per one part.

Significant producibility improvement and workplace safety can be obtained during large parts fabrication. Besides, systems based on robotic arms, AFP system suppliers offer gantry style machines (figure 8), which are typically used for large parts with a relatively simple shape [9].

Considering the latest Boeing and Airbus airplanes with a significant usage of composite parts, the necessity to increase composite parts manufacturing capability is obvious. Both largest airframe producers advertise introduction of AFP methods for production of their structures. Cost reduction of manufacturing processes and the need to increase production rate are key reasons for this choice, [10].

Thermoplastic tapes dedicated for AFP systems introduction is another great opportunity for part cost reduction. It is expected that the usage of AFP thermoplastic technology in primary structures will grow in the coming years [6].

7. CONCLUSIONS

On the basis of the conducted research the following conclusions have been drawn:

1. The newest Boeing and Airbus Large Aircraft designs contain up to 50% of composite parts by weigh. Airframers have been looking for effective technology for composite structure fabrication and succesfully introduced AFP technology into production.
2. The presented examples of accommodating AFP method into current production by Airbus and Boeing proves that AFP technology achieved high technology readiness level. It is expected that small and mid size airframe manufacturers will work on introducing this technology in their production.
3. World class Airframers with cooperation with AFP system producers are continuously conducting R&D work in this field. It is expected that aviation industry needs in the field of AFP technology R&D services will grow [11].
4. Considering AFP technology limitation related to parts shape, it is importand to design parts especially for this technology. That creates the need for cooperation between design office and AFP R&D center from the conceptual phase of a project.
5. AFP technology significantly reduces time of a part manufacturing, 8 tow head machine can reduce 20 times layup time in comparison with hand layup.
6. AFP technology ensures parts repeatability, especially in the field of fiber direction and fiber trim.
7. Although AFP technology with thermoset materials was successfully introduced into production, the usage of AFP technology with thermoplastic composites is still on the preliminary phase. AFP system equipped with a laser heat source allows to conduct R&D work with thermoplastic tape and in-situ fabrication. Combination of AFP method cost advantages and thermoplastic composite material properties advantages can be very beneficial.

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PRZEGLĄD SYSTEMÓW ZROBOTYZOWANEGO UKŁADANIA TAŚM KOMPOZYTOWYCH

Streszczenie

W artykule przedstawiono wyniki analizy w zakresie Zrobotyzowanych Systemów Układania Taśm Kompozytowych dedykowanych do produkcji kompozytowych struktur lotniczych. Zaprezentowano podstawy technologii układania taśm kompozytowych, przeanalizowano dostępne obecnie systemy w zakresie istotnych parametrów technologicznych. Przedstawiono architekturę współczesnych systemów układania taśm, rozpoczynając od niewielkich urządzeń przystosowanych do prac badawczo rozwojowych aż do dużych urządzeń przemysłowych. Opisano i poparto przykładami wprowadzenie tej metody do przemysłu lotniczego. Zaprezentowano typowe materiały przeznaczone dla technologii Zrobotyzowanego Układania Taśm Kompozytowych. Przedstawiono zalety i ograniczenia różnych konfiguracjach systemów pod względem wielkości wytwarzanych części, ich kształtu oraz używanych materiałów kompozytowych. Omówiono ekonomiczny aspekt użycia tej technologii w odniesieniu do tradycyjnej technologii ręcznego układania preimpregnatów kompozytowych.
Słowa kluczowe: kompozyty, struktury lotnicze, taśmy kompozytowe.