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V INTERNATIONAL SCIENTIFIC CONFERENCE

CONTEMPORARY TRENDS AND INNOVATIONS IN THE TEXTILE INDUSTRY

V MEĐUNARODNA NAUČNA KONFERENCIJA

SAVREMENI TRENDOVI I INOVACIJE U TEKSTILNOJ INDUSTRIJI

PROCEEDINGS

EDITOR:
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Belgrade, 15-16th September, 2022.
Union of Engineers and Technicians of Serbia
Dom inženjera „Nikola Tesla“

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ZBORNIK RADOVA

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PREFACE

The 5 th International conference "Contemporary Trends and Innovations in the Textile Industry" CT&ITI 2022, is co-organized by the Union of Engineers and Textile Technicians of Serbia, the Union of Engineers and Technicians of Serbia, the Faculty of Technology and Metallurgy in Belgrade, the University of Faculty of Technology, Shtip, North of Macedonia, Society for Robotics of Bosnia i Herzegovina and Balkan Society of Textile Engineering-BASTE of Greece.

The Ministry of Education, Science and Technological Development of the Republic of Serbia recognized the importance of this Conference, and thus, supported it.

The aim of this Conference is to consider current technical, technological, economic, ecological, R&D, legal and other issues related to the textile industry, then the application of contemporary achievements and the introduction of technical and technological innovations in the production process of fiber, textile, clothing and technical textile by applying scientific solutions in order to improve the business and increase the competitive advantages of the textile industry on the domestic and global market.

Leading scientists and experts from the Balkans and other countries, working at faculties, textile colleges and institutes, but also individuals who professionally deal with the issues at hand are taking part in this Conference.

The Conference program involves papers dedicated to the scientific and practical aspects of the following topics: Textile and Textile Technology, Textile Design, Management and Marketing in the Textile Industry and Ecology and Sustainable Development in the Textile Industry. The Conference program includes 48 papers, and a total of 116 participants from 14 countries: Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Greece, India, Latvia, North of Macedonia, Portugal, Romania, Russia, Serbia, Slovenia and Turkey.

Therefore, this Conference is an opportunity for establishing scientific, educational and economic cooperation of our country with other countries. Certain number of papers by domestic authors present the project results dealing with fundamental research and technological development, financed by the Ministry of Education, Science and Technological Development of the Republic of Serbia.

I would like to thank all those who have made it possible to organize the conference Contemporary Trends and Innovations in the Textile Industry and make it a success. First, I would like to thank the Scientific and Organizing Committee for working hard, spending countless hours and finding the best solutions for numerous organizational aspects of our Conference. Also, I would like to express my gratitude to all sponsors who believed in the importance of this Conference and co-financed it. I also thank all the other institutions that supported the Conference in various ways, because without their support, the Conference could not have been organized. Last but not least, I would like to thank plenary lecturers, all authors and co-authors and guests for their participation in the Conference.

On behalf of the Organizing Committee
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TABLE OF CONTENTS

DEFECT CHARACTERISTICS USING AUTOMATED FIBER PLASEMENT

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ABSTRACT: *Automated fiber placement (AFP) is an advanced manufacturing method for composites, which is especially suitable for large-scale composite components. However, some manufacturing defects inevitably appear in the AFP process, which can affect the mechanical properties of composites. These defects are the main limitation of the technology and can be hard to categorize or define in many situations. This paper provides a thorough definition and classification of all AFP defects. This effort constitutes a comprehensive and extensive library relevant to AFP defects. The defects selected and defined in this work are based on understanding and experience from the manufacture and research of advanced composite structure.*

Keywords: *automated fiber placement, manufacturing defects, mechanical properties, composites,manufacture*

KARAKTERISTIKE DEFEKTA KORIŠĆENJEM AUTOMATSKOG POSTAVLJANJA VLAKANA

APSTRAKT: *Automatsko postavljanje vlakana (AFP) je napredna metoda proizvodnje kompozita, koja je posebno pogodna za kompozitne komponente velikih razmera. Međutim, u AFP procesu se neizbežno pojavljuju neki proizvodni nedostaci, koji mogu uticati na mehanička svojstva kompozita. Ovi nedostaci su glavno ograničenje tehnologije i može biti teško kategorisati ili definisati u mnogim situacijama. Ovaj rad daje detaljnu definiciju i klasifikaciju svih AFP defekata. Ovaj napor predstavlja sveobuhvatnu i opsežnu biblioteku relevantnu za AFP defekte. Defekti odabrani i definisani u ovom radu zasnovani su na razumevanju i iskustvu iz proizvodnje i istraživanja napredne kompozitne strukture.*

Ključne reči: *automatizovano postavljanje vlakana, proizvodni defekti, mehanička svojstva, kompoziti, proizvodnja*

1. INTRODUCTION

Novel composite manufacturing processes offer greater control over tailored fiber orientation. An application of such enabling technology is based on introducing continuous fiber either through fused filament additive manufacturing [1]. These manufacturing methods [1, 2] can be used to rapidly produce composites with greater flexibility by optimizing manufacturing parameters based on loading conditions through a tailored stiffness structure. The central focus of the work is on automated fiber placement (AFP), which is a state-of-the-art high throughput method that allows for the fabrication of advanced composites structures [3].

AFP technology can be used not only for producing thermosetting or thermoplastic composites but also for dry fiber placement [4,5,6]. An AFP machine usually consists of a placement head and functional mechanical structure (a robotic arm or gantry structure). (Figure.1)

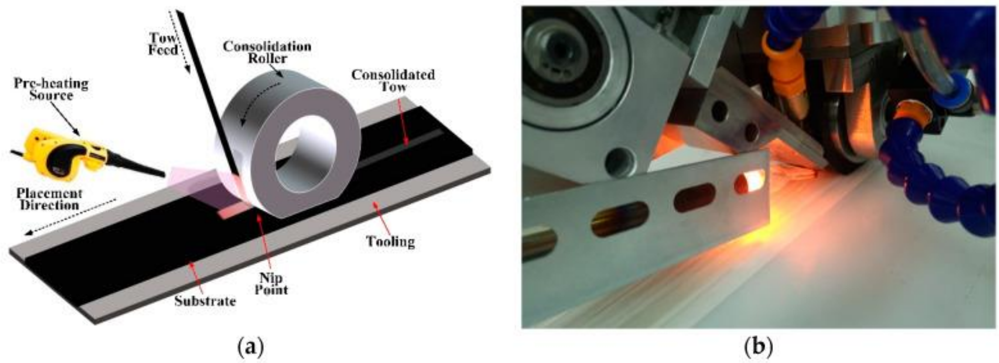


Figure 1: The automated fiber placement (AFP) working principle and AFP machine produced by Coriolis: (a) AFP working principle [7], (b) AFP machine produced by HIT

Due to the complexity of the AFP manufacturing process, especially multiple process parameters, prepreg defects, and manufacturing errors, the laminates are not exempt from imperfections, such as gaps and/or overlaps, twisted tows, fiber waviness, and air pockets, which often appear in the final component, thereby affecting the mechanical performance [8,9,10,11,12,13,14,15]. The contribution of literature [16] has been to classify the defects during the AFP process, including the following four categories:

- Positioning defects (gaps, overlaps, missing tows, twisted tows, etc.);
- Bonding defects (bridging, air pockets, etc.);
- Foreign bodies;
- Tow defects.The different types of defects are shown in Figure 2.

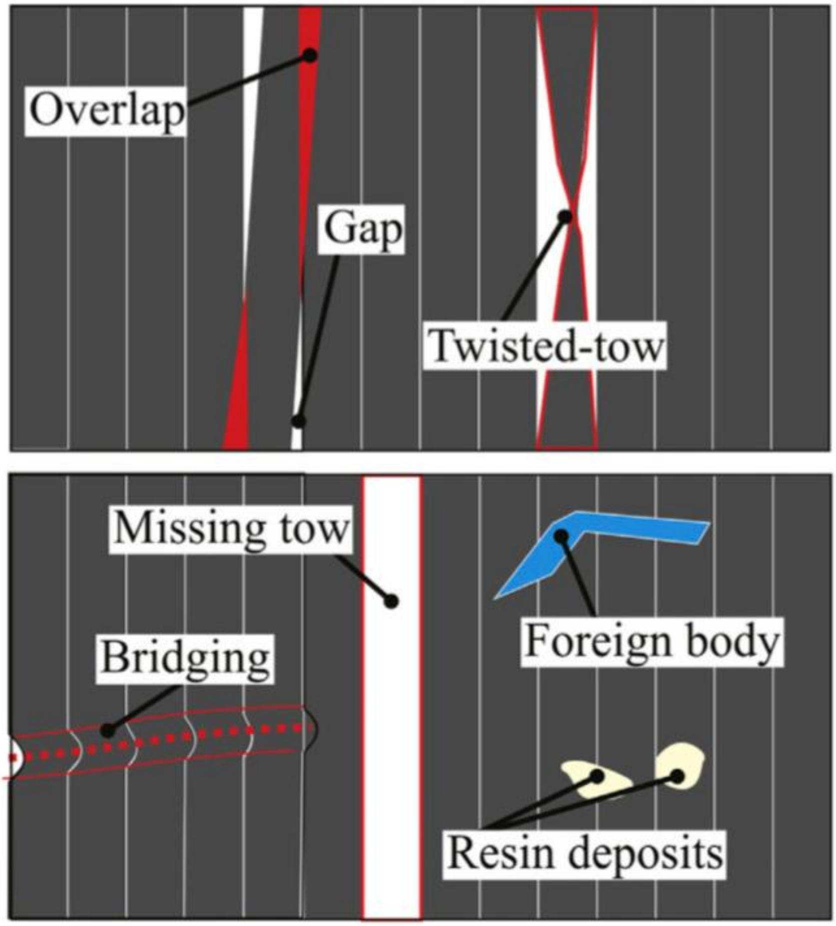
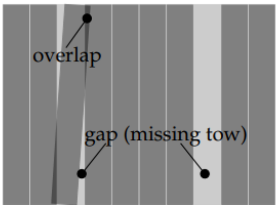


Figure 2: Defects occurring during the automated fiber placement process

2. EXPERIMENTAL

Gaps and overlaps (Figure 3) are the imperfections that occur most frequently during the ATL/AFP process. Essential influencing factors for their development are the process-ability of the material as well as the machine parameters [17]. Depending on the material quality each tow undergoes width fluctuations. This results in gaps (negative tolerance) or overlaps (positive tolerance) between adjacent tows and courses [18].
A gap is when two adjacent tows are not perfectly laid up next to each other and there is a gap between the two. An overlap is when the two adjacent tows are overlapping onto each

other. The most common cause of gaps and overlaps is steering during layup since, the tows in a course will not fit together perfectly, especially when adopting a parallel coverage strategy. However, gaps and overlaps can naturally occur outside of steering if laying up over a complex 3D tool surface.



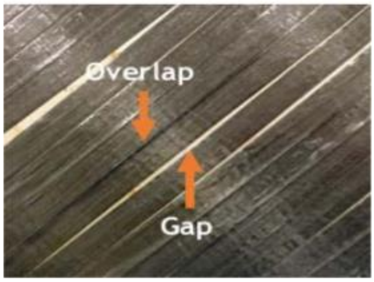
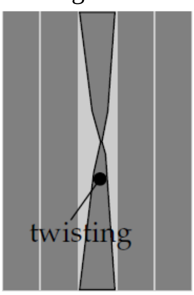


Figure 3: Schematic and actual representation of gaps and overlaps within a ply

Twisting of individual tows (Figure 4) can already occur within the material supply and payout system of the AFP end effector (cf. Figure 4) due to the movement of the AFP machine along the fiber placement path [19]. Width fluctuations of the fiber material enable sideways movements within the material guiding system resulting in a flip over of individual tows. Fiber steering can also provoke the twisting of tows [19]. Consequently gaps arise in the immediate vicinity of the
twisted tow [20, 21]. As secondary imperfections, fiber waviness might evolve in adjacent plies [19]. Twisted tow could be initiated by folding, in which the fold grows and completes a full turn rather than unfold (folded tow could be considered incomplete twist). Friction between guide holes along a long/complex tow path and a tacky tow may cause twisting due to head rotation during bi-directional layups.



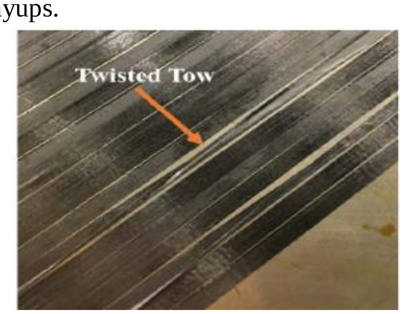


Figure 4: Schematic and actual representation of a twisted tow wihtin a ply

Missing Tow - this defect typically occurs when an entire tow does not correctly adhere and falls off the surface or is not successfully fed onto a surface from the spools. The resulting missing tow is very similar to a gap, and in fact can be considered as a gap with a size equal to a tow width. Missing tows are caused by either discontinued material feeding into the machine head or layup of a tow with insufficient tack adhesion. (Figure 5).

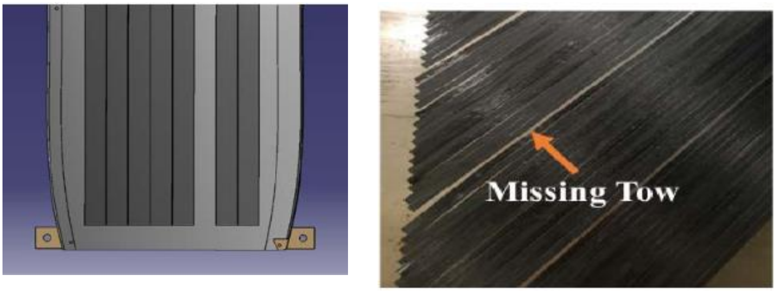


Figure 5: Missing tow CAD and actual representation

A **bridged tow** does not fully adhere to the concave surface (female tool portion) or a re-entrant corner or ramp-up area over which the tows are being laid up on, leaving a gap between the radius of the concave tool surface and the tow. The main causes of a bridged tow are too much tension on the tow, which will force the tow to lift up, or insufficient tack adhesion to the surface being laid up on due to the roller not providing full contact with the substrate material. (Figure 6).

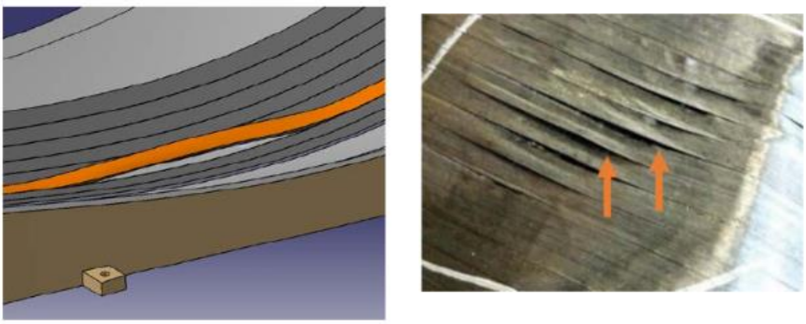


Figure 6: Bridging CAD and actual representation

A **foreign object debris (FOD)** defect is when a small piece of composite material, either carbon fiber "fuzz-ball" or "resin ball" that has collected on surfaces of the head or other debris from the production area fall onto the part during layup. This results in a small excess volume of material on the ply if laid up over.

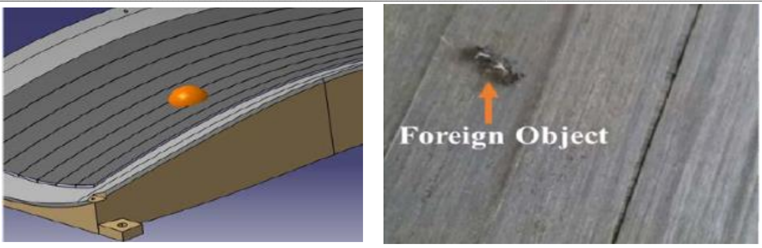


Figure 7: Foreign object debris (FOD) CAD and actual representation

3. RESULT AND DISCUSSION

In summary, the types of position defects and their formation reasons during the AFP process have been thoroughly analyzed. The defects, such as gaps, overlaps, and twisted tows, can be induced by the combination of many factors, including machine tool errors, unreasonable process parameters, irrational angle planning, tow width limitation, and the in-plane bending deformation of a tow, etc. These defects may result in the formation of other defects. For instance, the gaps can lead to resin-rich areas or fiber waviness that affect the mechanical properties of composites. Moreover, the influence of defects on the mechanical properties of composites has been studied in depth, including the tensile, compression, shear, and even fatigue and vibration properties. However, not all defects hurt mechanical properties. For example, the overlaps can result in an absolute improvement in the compression strength. With this feature, we can avoid unfavorable defects as much as possible according to the different performance requirements of the parts or use favorable defects to reduce the impact of the unfavorable defects. The "overlap method" utilizes this principle, which can reduce the adverse effects of gap defects by controlling the translation distance to form overlaps between adjacent tows, but this method increases the thickness of the local regions. However, if the current review shows anything it is that the effects and interaction of gaps and overlaps in composite laminates is very complex, so we should be more cautious when this method is applied. This requires that, when a single defect is used to improve some performance, the complex formation mechanism of the defect and the interaction between the defects should be first understood thoroughly. To limit or control the effects of defects, researchers have proposed some measures to reduce defects, such as the tow-drop method, the staggering method, and CTS, but each has its scope and shortcomings.

4. CONCLUSION

This paper described a AFP defects. In categorizing the defects, the defects can be defined from the viewpoint of the designer, the process planner, the machine operator, and even the inspector. This allows for a rich understanding of each individual defect which can help to fully answer the following questions:

- Can the formation of a certain defect be anticipated based on knowledge of the part geometry, machine parameters, and process planner decisions? - Can the existence of a certain defect be confirmed based on available inspection systems such as profilometry, heat, ultrasounds or other technologies? - Can the significance of the existence of the defect be understood, in a certain size/shape, on the overall integrity of my structure? - Can defect progression be explained to the point of the performance effect and how it can initiate failure?

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