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AŞINDIRICILI SU JETİ (ASJ) İLE KESİMDE BASINÇ DEĞİŞİMİNİN KARBON FİBER TAKVİYELİ POLİMER MALZEMELERDE DELAMİNASYON OLUŞUMUNUN ARAŞTIRILMASI

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ÖZET

Aşındırıcı Su Jeti (ASJ) ile kesim başta havacılık olmak üzere teknolojinin birçok alanında oldukça geniş bir kullanım alanına sahiptir. Söz konusu kesim yöntemi, basınçlandırılmış su jeti hüzmelerinin içerisinde yer alan aşındırıcı 100-200 µ büyüklüğündeki taneciklerin malzeme üzerine yüksek hızla püskürtülmesi sayesinde gerçekleştirilmektedir. ASJ ile kesimde malzeme türü, basınç, ilerleme hızı ve su jeti çapı kesim sonrası yüzey kalitesi açısından oldukça önemlidir. Kesim esnasında, termal ve mekanik yüklerin az olması önemli bir avantajdır. Isı Tesisi Altında Kalan Bölge (ITAB) oluşmamakta ve malzeme kristal yapısında ısıdan kaynaklanan bozulmalar meydana gelmemektedir. Diğer taraftan kesim işlemi sırasında kullanılan aşındırıcı tanecikler filtre edildikten sonra tekrar kullanılabilmektedir. Taneciklerin tekrar kullanımı, ASJ ile kesim prosesinin işletme maliyetini düşürmektedir. Bu bildiride bahsi geçen, Karbon Fiber Takviyeli Polimer (KFTP, Carbon Fiber Reinforced Polymer-CFRP) malzemeler ise başta havacılık olmak üzere otomotiv, denizcilik gibi endüstriyel alanlarda çok yaygın bir şekilde kullanılmaktadır. KFTP malzemeler, çelik ve aluminyum malzemelere göre düşük yoğunluğa sahipken görece mukavim malzemeler olarak kabul edilmektedir. ASJ, KFTP malzemelerin kesimlerinde oldukça yaygın olarak kullanılan bir prosestir. Bu araştırma çalışmasında test numuneleri önce UD ve Twill olarak iki farklı grupta, Peel-Ply adı verilen soyma kumaşı ile beraber otoklavda kürlenmiştir. Ardından, ASJ ile KFTP malzemelerin kesimleri gerçekleştirilmiştir. Daha sonra kesilen test kuponları Taramalı Elektron Mikroskobu (TEM, Scanning Electron Microscope-SEM) altında incelenmiştir. Çalışma sonunda, basınç değişiminin, KFTP malzemelerinin delaminasyon üzerinde etkili olduğu elektron mikroskopu sonuçları ile ortaya konmuştur.

Anahtar Kelimeler: Aşındırıcı Su Jeti (ASJ), Delaminasyon, Karbon Fiber Takviyeli Polimer, Taramalı Elektron Mikroskobu

***Yazar Notu:** Yazarın "Aşındırıcı Su Jeti ile Kesmede Malzeme, Basınç, İlerleme Hızı ve Su Jeti Çapının Yüzey Kalitesine Etkisinin Analizi" başlıklı doktora tezi ile ilgilidir.*

THE RESEARCH OF THE DELAMINATION FORMATION REGARDING PRESSURE CHANGE IN CUTTING WITH ABRASIVE WATER JET (AWJ) FOR CARBON FIBER REINFORCED POLYMER (CFRP) MATERIALS

ABSTRACT

The Abrasive Water Jet (AWJ) cutting has a wide range of usage in many areas of technology, especially in the aviation industry. The mentioned process is realized by spraying the 100-200 µ size abrasive particles on the material at high speed within the pressurized water jet beams. When cutting with ASJ, material, pressure, cutting velocity, and water jet diameter are very important in terms of surface quality after cutting. It is an important advantage that thermal and mechanical loads are low during cutting. During the cutting process, Heat Affected Zone (HAZ) and hence deterioration in the crystal structure of the material due to HAZ do not occur. On the other hand, abrasive particles used during the cutting process can be reused after filtering. The reuse of abrasive particles reduces the operating cost of the AWJ cutting process. Carbon Fiber Reinforced Polymer (CFRP) materials mentioned in this paper are widely used in the industries such as aviation, automotive, and marine. While CFRP materials have low density compared to steel and aluminum materials, they are considered to be relatively strong materials. In general, AWJ is a process widely used for cutting CFRP materials. In this research study, the test samples were cured in two different groups as UD and Twill with a peeling fabric called Peel-Ply using an autoclave. Subsequently, cutting of KFTP materials was carried out using the AWJ process. Then the cut test coupons were examined under Scanning Electron Microscope (SEM). At the end of the study, it was revealed by the electron microscope results that the pressure change affects the delamination of CFRP materials.

Keywords: Abrasive Water Jet (AWJ), Carbon Fiber Reinforced Polymer (CFRP), Delamination, Scanning Electron Microscope (SEM)

Author's Note: *It is related author's doctoral dissertation titled " Analysis of Material, Pressure, Cutting Velocity and Water Jet Diameter's Effect on the Surface Quality for the Water Jet Cutting"*

1. INTRODUCTION

The airplanes operate in extraordinary and challenging environments. During a cruise flight outside temperature is about -55/-60 ^{0}C and the atmospheric pressure is almost one-fourth of the Mean Sea Level (MSL). In other words, during a cruise flight at the regular altitude which is generally 33.000 feet, the aircraft floats through a vacuumed environment approximately three times colder than a deep freezer. Obviously, these unusual operating conditions, need more accurate technologies based on precise manufacturing applications. It is noteworthy that, the aviation industry has been recognized for its ability to design and produce structural elements made of advanced materials, and it has risen to the top of this field in comparison to other industries (Garcia, Ares, Martinez and Gómez, 2019).

The weight is an important input that affects the characterization of flight. It is out of the question that a lighter aircraft will have tighter maneuver characteristics than a heavier one. Maneuverability is important in military aviation since they operate in more risky conditions than commercial passenger aircraft (Purton and Kourousis, 2014). On the other hand, weight has a direct impact on the Direct Operational Cost (DOC) due to fuel consumption. In a regular flight of an airliner, the percentage of fuel consumption has the highest bid with 33,4% while the Aircraft Ownership is 10,6% and Maintenance, Repair and Overhaul (MRO) is 9,4% (Saracyakupoglu, 2019). In this manner, when the aviation industry is investigated it will be observed that the airplanes' structures were changed from wood to steel, from steel to aluminum, and lastly from aluminum to composites such as Carbon Fiber Reinforced Polymer (CFRP). The weight and DOC constraints forced the aeronautical engineering teams to make studies for exploring the novel materials such as Carbon Fiber Reinforced Polymer (CFRP). The densities of the steel, aluminum, and composites are 7,8 gr/cm^3 2,7 gr/cm^3, and 1,6 gr/cm^3 respectively. When CFRP is compared to aluminum it can be said that the aluminum is heavier, corrodes easily, is ductile, conducts well, and bends easily. CFRP has outstanding physical and mechanical properties, including a high strength-to-weight ratio, high harm tolerance, and high fatigue and corrosion resistance. Carbon fiber is lightweight and does not bend, but it can shatter. As two of the most well-known commercial passenger aircraft types, Boeing 787 Dreamliner and Airbus A350 XWB have %50 (Aly, 2017) and %53 (Bachmann, Hidalgo, Bricout, 2017) composite materials respectively.

In the open literature, there are many studies on CFRP usage in the aviation industry. The drilling operations with legacy methods of the CFRP parts were inspected. In this research, it was found that the thrust force and torque produced in drilling CFRP composite material are heavily influenced by the machining conditions. It was also claimed that lowering the drill machine's feed-rate reduced the delamination while drilling CFRP (Nagaraj, Uysal and Jawahir, 2020). In another study, it was investigated to drill a hole using an Abrasive Water Jet (AWJ) The researchers manufactured CFRP coupons and drilled them using AWJ to inspect the delamination. Conclusionally they found the best delamination control technique might be a backup plate followed by a pre-drilled hole (Phapale, Singh, Patil, Singh, 2016). The kerf surface quality was also inspected by the researchers in terms of delamination. The authors focused on the AWJ machining of multidirectional CFRP in terms of lamination. They made cutting using a Flow 3-Axis CNC AWJ machine. For two different configurations with different lay-ups they found that high operating pressure, low feed rate might increase the kerf's surface quality (El-Hofy, Helmy, Escobar-Palafox, Kerrigan, Scaife, El-Hofy, 2018). In terms of the low feed rate, the result of the mentioned study is consistent with the author's doctorate thesis (Saraçyakupoğlu, 2012). Up to a certain level, decreasing the feed rate might be helpful for increased surface quality.

In this proceeding, the results of the delamination inspection for peel-plied and non-peel-plied CFRP coupons will be presented.

2. RESEARCH AND FINDINGS

2.1. Experimental Work and Methods

The fiber fabric, enforced by the matrix resin, contributes tensile strength to a CFRP component, improving performance properties such as strength and stiffness while reducing weight. In this research study, for manufacturing the test coupons, the 2x2 Twill Weave Carbon Fiber which is shown in Figure 1 was used as reinforcement material and regular resin was used as matrix material.

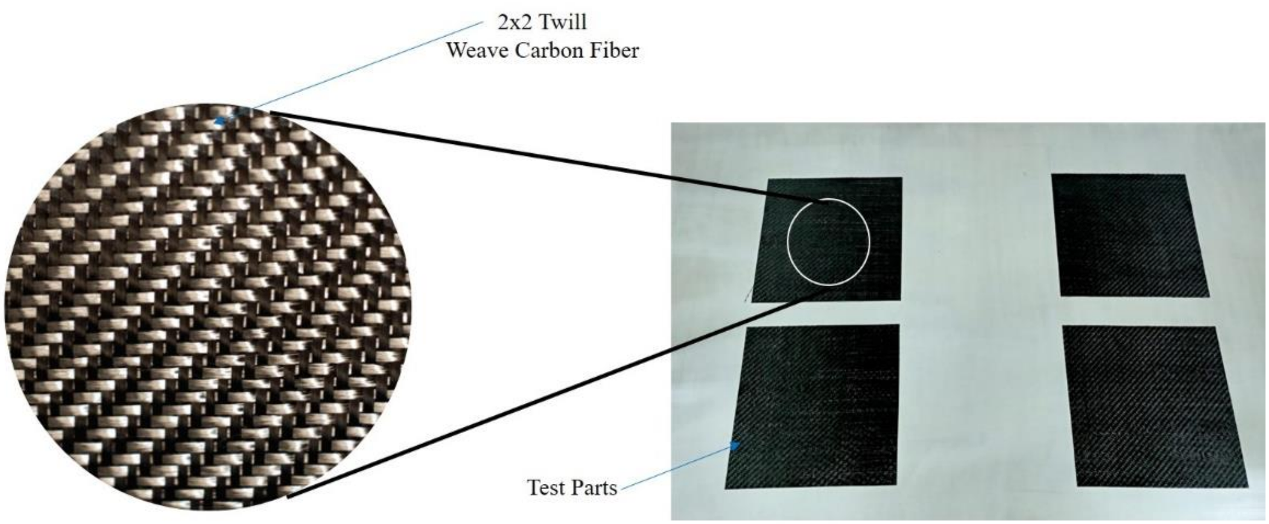

Figure 1. Twill Weave Carbon Fiber Fabric Under Preparation Stage

During CFRP coupon manufacturing, the parameters were set as 4 lay-ups [90°/0°/90°/0°]. After the resin was poured, the parts were covered with ply-peel and then vacuumed with the value of 600 mm/hg. As a next step, the parts were cured approximately 8 hours in the autoclave that was set to 120 ^{0}C degree of temperature and 6,9 Bar of pressure.

The peel ply is an additional layer of fabric material applied to the composite's outer surface during production. In general, this layer will be peeled off before bonding at some point in the future. A woven fabric, glass, nylon, or other synthetic material is used for the peel ply. The peel ply fabric absorbs some of the matrix resin during the cure cycle of the composite fabrication process and becomes an integral part of the laminate. The peel ply is stripped before bonding, fracturing the resin between it and the first layer of reinforcement. After removing the peel-ply, a roughened matrix resin surface to which the adhesive can be applied is left as shown in Figure 2.

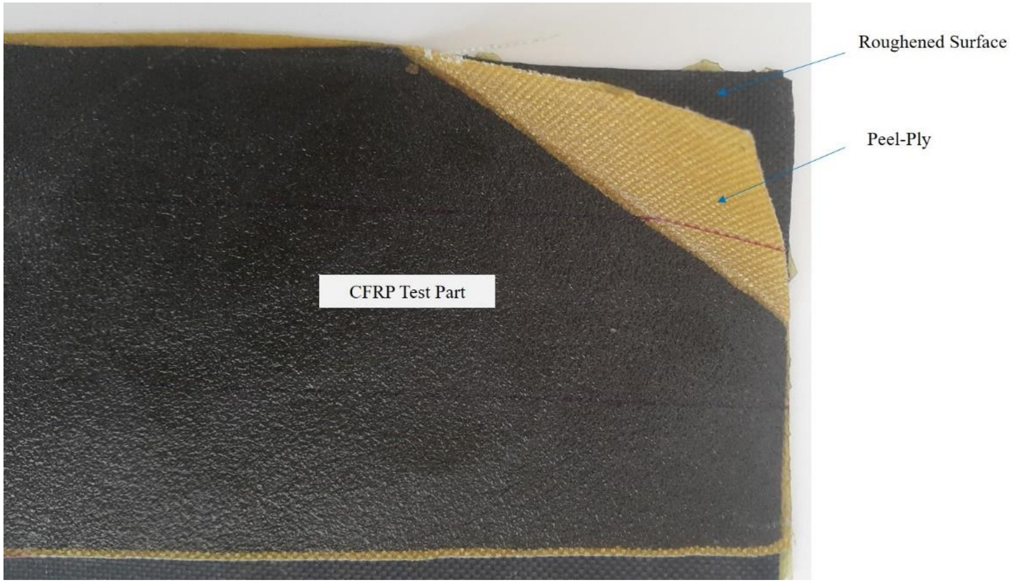

Figure 2. The Peel-Ply and Roughened Surface of the CFRP Test Part

As it was mentioned before, the AWJ cutting requires a high-pressure water jet with an abrasive powder suspended in it. The jet is applied at the workpiece and hence cutting the part in the desired form. In Figure 3, a generic illustration of an AWJ machine is shown in Figure 3 (Hashhish, 1991) with a photograph of the nozzle taken in the shop.

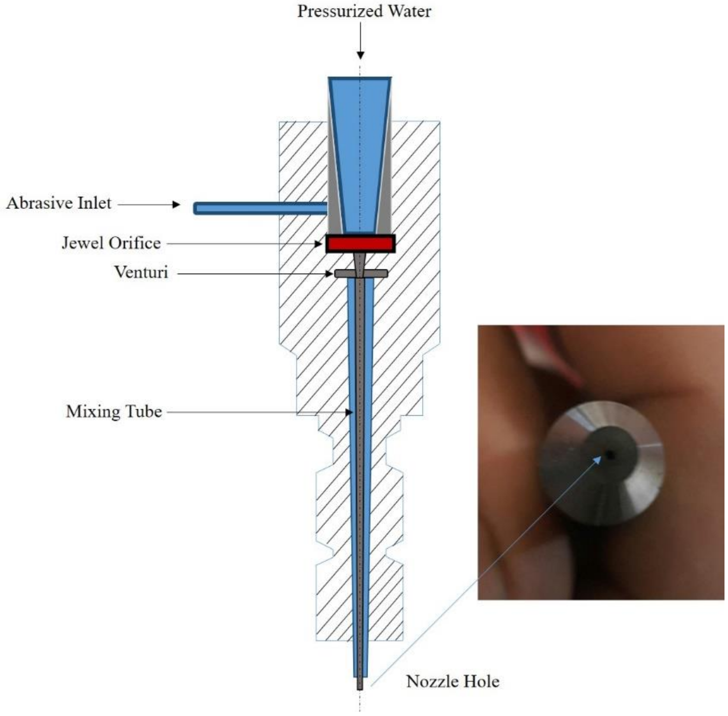

Figure 3. The Illustration of AWJ Machine and Nozzle Hole

During cutting operations, the nozzle diameter is 0,76 mm, the feed rate is 1000 mm/min, the pressure was set to 2000 bar and 4000 bar respectively. As it is presented in Figure 4 (a), the sample parts were firstly cut with peel-ply and as shown in Figure 4 (b) cut after peel-ply had been removed.

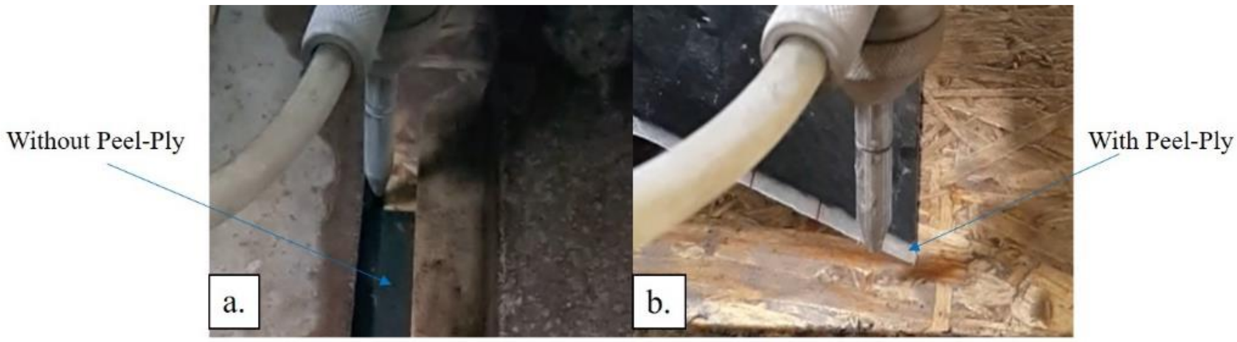

Figure 4. The CFRP Sample Part with Peel-Ply, (b).The CFRP Sample Part without Peel-Ply

The kerf geometry which is made by the cutting waterjet and the surfaces that were subjected to inspection is given in Figure 5.

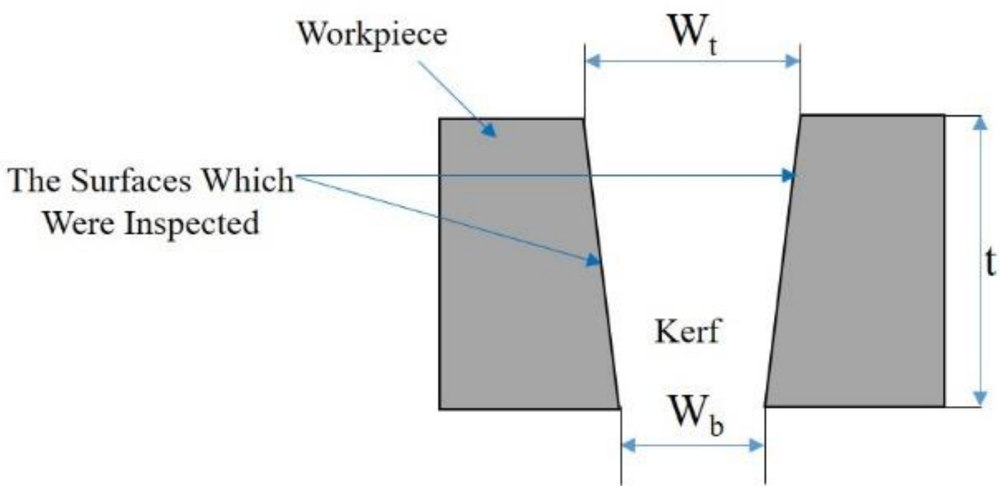

Figure 5. The Kerf Geometry and the Surfaces Subjected to Inspection (El-Hofy, Helmy, Escobar-Palafox, Kerrigan, Scaife, El-Hofy, 2018)

It is noteworthy that the kerf taper can be calculated from the equation given in Formula (1).

$$\text{Kerf taper} = \frac{W_t - W_b}{2t} \qquad (1)$$

After CFRP sample parts that had been cut using AWJ were sent to the laboratory for microscopic inspection under Scanning Electron Microscope (SEM). As shown in Figure 6, the cut sections were inspected in terms of understanding the delamination behavior depending on being cut with or without peel-ply.

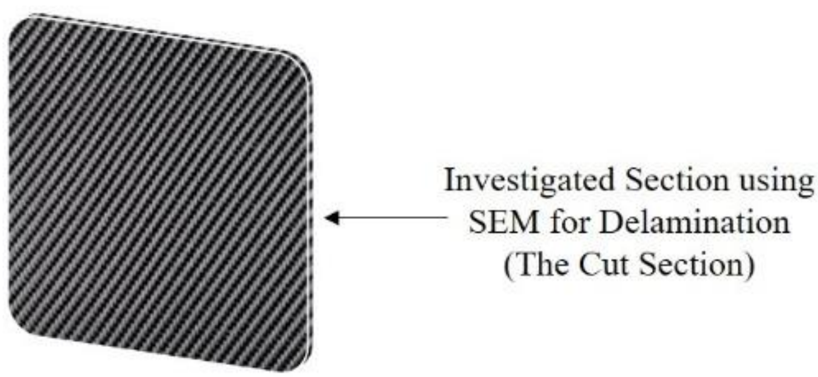

Figure 6. The Cut Section Investigated Using SEM

2.2. Experimental Results and Discussion

In this research, an experimental study is made in terms of understanding the behavior of AWJ application over CFRP samples with or without peel-plies. Basically, the steps are considered in 3 phases as the manufacturing, AWJ cutting, and SEM inspections. For each phase the results are given uniquely as follows;

2.2.1. Peel-Plied CFRP Sample Manufacturing Phase

All of the samples were manufactured with peel-plies. The peel-plied CFRP samples were manufactured under the conditions given in Table 1.

Table 1. The parameters of the CFRP using Autoclave

Peel-Plied CFRP Sample Manufacturing Parameters					
Number of Lays	Lay-Up Directions	Vacuum	Temperature	Autoclave Pressure	Duration
4	90°/0°/90°/0°	600 mm/hg	120 ^{0}C	6,9 Bar	8 hours

At the end of this study, it can be claimed that as a common CFRP composite the mentioned parameters may be used for manufacturing. Totally 4 samples were manufactured.

The feel test, visual control, and bending tests were applied to the manufactured plates. Neither stripping nor significant manufacturing defect was determined.

2.2.2. Abrasive Water Jet (AWJ) Cutting Phase

For the AWJ cutting process, peel-ply was stripped from two of the plates. The parameters of the AWJ are provided in Table 2.

Table 2. The AWJ Cutting Parameter for Peel-Plied or Non-Peel-Plied (Naked) Parts

	Abrasive Water Jet (AWJ) Cutting			
P/N	Peel-Ply	Nozzle Diameter	Feed/Rate	Pressure
#1	With Peel-Ply	0,76 mm	1000 mm/min	4000 bar
#2	With Peel-Ply	0,76 mm	1000 mm/min	2000 bar
#3	After Peel-Ply Removed	0,76 mm	1000 mm/min	4000 bar
#4	After Peel-Ply Removed	0,76 mm	1000 mm/min	2000 bar

2.2.3. Scanning Electron Microscope (SEM) Inspections

A total of 4 different inspections were made in order to cross-check the parts in groups of two with each other. Sample #1 and sample #2 are with pee-ply and sample #3 and sample #4 without peel-ply.

For cross-checking with each other two peel-plied and two non-peel-plied parts were examined in total four. An accelerating voltage of 20 kV, a spot size of approximately up to 20 µm, and 5.0 KX magnification parameters were used during inspection. In Figure 7, the results of the parts which were cut while the peel-ply on them are shown.

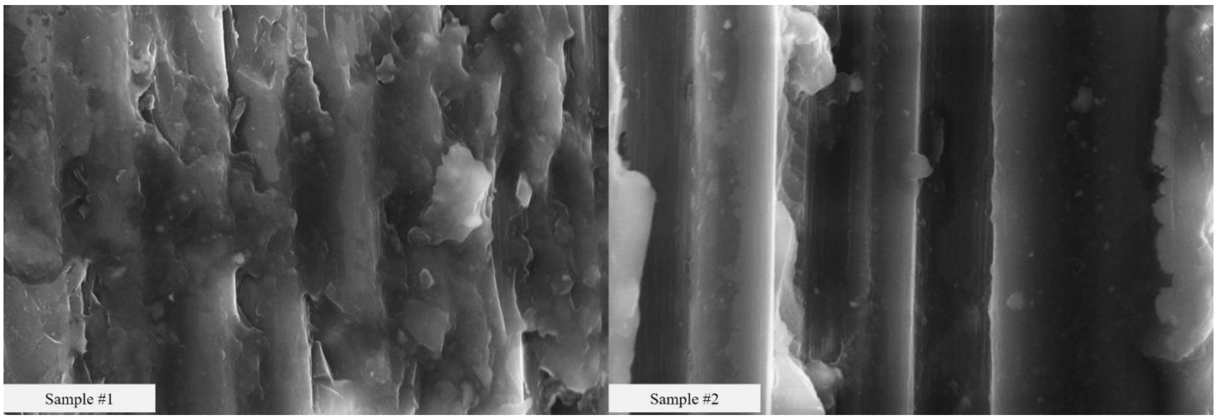

Figure 7. The SEM Images of the Peel-Plied Parts

In Figure 8, the results of the parts which were cut after the peel-plies are removed are shown.

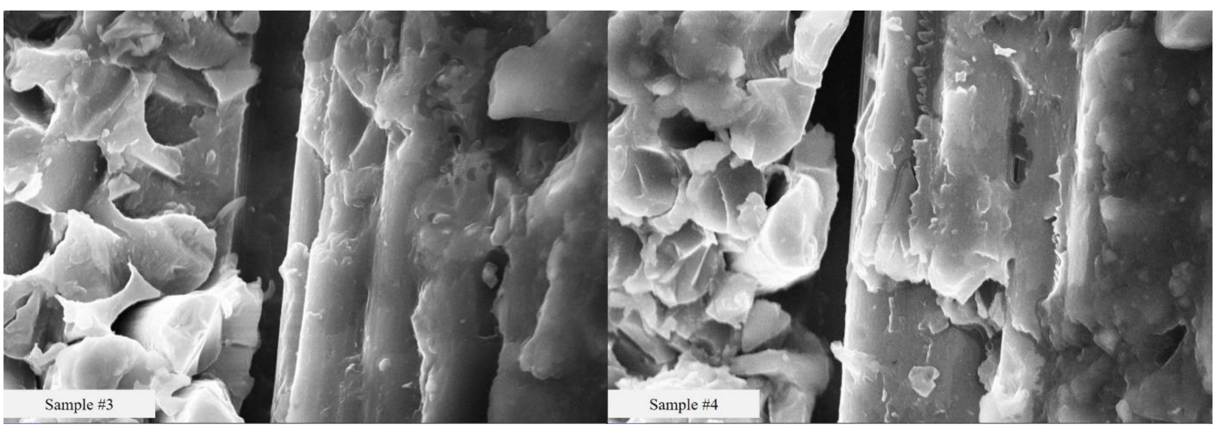

Figure 8. The SEM Images of the Non-Peel-Plied Parts

Comparing Figure 7 and Figure 8, it can be claimed that delamination is lower for the parts shown in Figure 7.

3. Conclusion

This investigation presented the mechanisms of delamination formation of the peel-plied and non-peel-plied CFRP plates which are subjected to the AWJ cutting process. Some concluding remarks, drawn from the results of the present study may be listed as follows:

- The delamination formation is mainly affected by the parameters of the manufacturing and AWJ Process,
- The pressure change during AWJ may conclude with slight delamination as seen in Figure 7,
- However, being peel-plied or non-peel-plied may sharply affect the delamination formation as seen in Figure8,
- The use of peel-ply during AWJ cutting may positively contribute to decreasing delamination formation.
- The possible further precautions for preventing the delamination may be outlined as the concentration on the peel-ply structure rather than pressure change and usage of proper parameters for both manufacturing and AWJ cutting processes.
- For future studies, produce more samples with different parameters changing the cutting pressure, and perform mechanical tests are recommended.

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