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Experimental Study of Preload and Bolt Arrangement on Composite Joint Performance in Megawatt Wind Turbine's Nacelle Cover and Nose Cone

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ABSTRACT: The nacelle cover and nose cones of most megawatt wind turbines are made of composite sheets. Due to the complex shapes, geometries, and large dimensions of these components, they are composed of several parts that must be assembled using non-permanent mechanical joints, such as bolts. Therefore, it is very important to consider all the effective parameters that affect composite joints. One of the most critical design parameters for bolt connections is the amount of bolt preload or tightening torque. However, increasing the preload without caution is not feasible due to the composite material present on both sides of the joint, as this can potentially damage the composite sheets. As a result, this paper aims to evaluate experimentally the effect of bolt preload or tightening torque on composite joints. To achieve this, identical specimens were fabricated, each with a different bolt tightening torque ranging from 2 Nm to 50 Nm. These specimens were then subjected to a tensile load. After determining the optimal preload force, four different types of arrangements were experimentally tested to find the best bolt arrangement. Finally, by examining various aspects, the best arrangement for connecting different parts of the nacelle cover and nose cone was determined.

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1- Introduction

Composite joints play a vital role in the structural integrity of wind turbine components [1]. This experimental study aims to investigate the effect of preload and bolt arrangement on the performance of composite joints in the nacelle cover and nose cone of a Megawatt wind turbine. The study focuses on analyzing the mechanical behavior of composite joints under various loading conditions and bolt configurations. A series of experimental tests are conducted to evaluate the performance of the composite joints. These tests could include tensile, compressive, and fatigue loading scenarios, simulating the extreme operating conditions experienced by wind turbine components. The composite specimens are constructed using glass fiber-reinforced polymers, widely used in wind turbine applications for their high strength-to-weight ratio. Figure 1 shows the shell of the nacelle and the nose of the turbine. The connections between the parts have been determined based on the results of this article and the tests conducted. As can be observed, the dimensions of the shell are quite large due to the significant size of the equipment inside the megawatt wind turbine nacelle. It has a length, width, and height of 14 meters, 5 meters, and 4 meters respectively. Furthermore, the nose consists of four main parts, with the largest part being a circular shape measuring 4.5 meters in diameter.

The preload, the initial axial force on the bolt, is varied to analyze its effect on the joint performance. Different bolt arrangements are also investigated. The experiments utilize a specialized testing rig capable of applying axial and shear loads on the composite joints, simulating realistic conditions.

Preliminary results indicate that the preload significantly affects the mechanical behavior of the composite joints. Higher preload values result in improved joint performance by minimizing the risk of bolt loosening and improving load transfer efficiency. Additionally, the bolt arrangement plays a crucial role in distributing loads across the joint interface and reducing stress concentrations.

The findings from this study will provide valuable insights into the optimization of composite joint design for wind turbine nacelle cover and nose cone applications. Understanding the influence of preload and bolt arrangement on joint performance will enable engineers to enhance the structural integrity and reliability of wind turbine components, contributing to the efficiency and durability of Megawatt wind turbines.

2- Investigation of the effect of pre-load on the behavior of composite connections

The geometry and testing method of the specimens were performed according to ASTM D 5961/D 5961 M standard [2]. The thickness of all specimens is within the standard

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Fig. 1. Nasal Cover of the two-megawatt wind turbine is constructed using composite materials

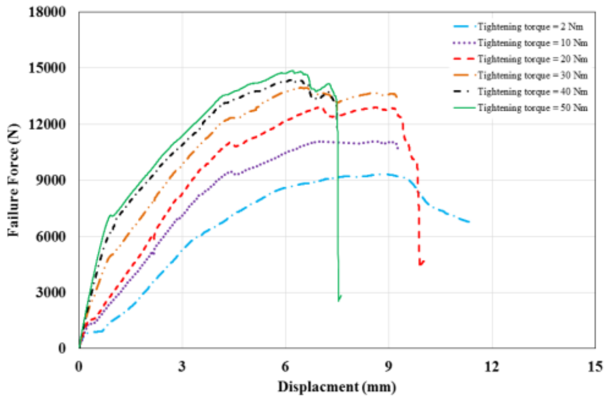

Fig. 2. Force-displacement diagram for different samples under tensile loading

range of 3 to 5 millimeters. The remaining dimensions of the specimens and the geometric parameters are defined according to the standard. These parameters include: $w/d = 4$, $e/d = 3$

To accurately determine the effect of preload on the behavior of the connection, only the preload parameter has been changed among all the constructed specimens, while the other material and geometry parameters remain constant so that the effect of preload on the breaking force of the connection can be studied independently. In these specimens, the tightening torques of the bolts that generate the preload forces of the connection are 2, 10, 20, 30, and 50 Newton meters. Five specimens have been tested for each torque to minimize testing and specimen fabrication errors and the ISO f7/H10 drilling standard has been used in the fabrication of all the specimens [3].

3- The effect of bolt arrangement on the behavior of composite connections

After determining the effective and optimal preload in composite joints, the goal is to determine the self-arrangement of the joint. Due to the large size of the components, using smaller bolts can increase the assembly, inspection, and repair time required for the parts, thereby increasing the cost of wind turbine construction, repair, and maintenance. On the other hand, increasing the bolt size can lead to a lack of joint integrity due to increased distance between the bolts. Therefore, accurate determination of the bolt size used is of great importance in joint design. For this reason, various joints with different arrangements have been evaluated in this section. To find the mentioned effect, the following 4 arrangements have been used: 5 M8 bolts, 4 M10 bolts, 3 M12 bolts, 2 M16 bolts.

4- Results and Discussion

Figure 2 represents the force-displacement diagram for all tested samples with tightening torques ranging from 2 to 50 Newton-meters. As shown in this figure, increasing the tightening torque and pre-load of the connection not only

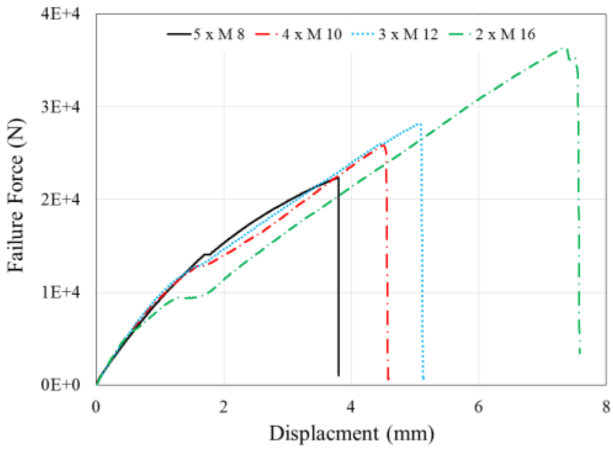

Fig. 3. Force-displacement diagram for different samples

increases the breaking force but also affects the slope of the force-displacement curve. The change in slope is due to the compression of both sides of the connection and changes in friction between the two connected parts. With an increase in pre-load, these breaks also occur at higher forces, indicating a better and stronger adhesion between the two sides of the connection. Another effect of increasing the pre-load or tightening torque is a decrease in the overall displacement of the connection at the point of failure. This, along with an increase in the reliability factor of the connection, leads to better integration of the components and improved performance of the structure formed by these different parts.

Figure 3 depicts the force-displacement graph for all tested configurations. As seen in the graphs, the configuration with two M16 bolts has the highest breaking force. The breaking force for this configuration is 63% higher than the breaking force for the connection with five M8 bolts. The displacement also increases as the breaking force in the connections increases. Another notable point is that at the beginning of

Fig. 4. State of bolted joint using five M8 bolts after the failure

the test, the slope of the force-displacement graph is the same for all cases. Then, as the force increases, this slope breaks and changes. This breaking point is when the tensile force in the connection exceeds the friction force and the two parts of the connection slide against each other.

Figure 4 shows the State of the bolted joint using five M8 bolts after the failure. As can be seen, the failure started from the first bolt. It began from the edges of the drilled hole and continued toward the edge of the component. Furthermore, this delamination occurs with extensive layering of the composite around the hole. It is also observed that the failure and delamination of the composite only occurred in one of the bolts, while the rest of the bolts are intact and in contact with the composite and the surrounding composites.

5- Conclusions

In summary, the following results can be stated:

- Increasing the torque applied to the bolts has a significant and noticeable effect on the break force of the connections. Increasing the torque from 2 to 50 Nm leads to a 55% increase in the break force of the connections.
- The breaking force of M16 connection is 67% higher than that of M8 connection. the resistance to slippage between components in M8 connection is 147% higher than in M16 connection. Resistance to slippage is important because after passing through this region, the bolt shaft comes into contact with the composite edge of the component, effectively loading the round edge hole in the composite piece, which can cause deformation.

References

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