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DEVELOPMENT OF AUTOMATED SEALING SYSTEM FOR AIRCRAFT COMPONENTS

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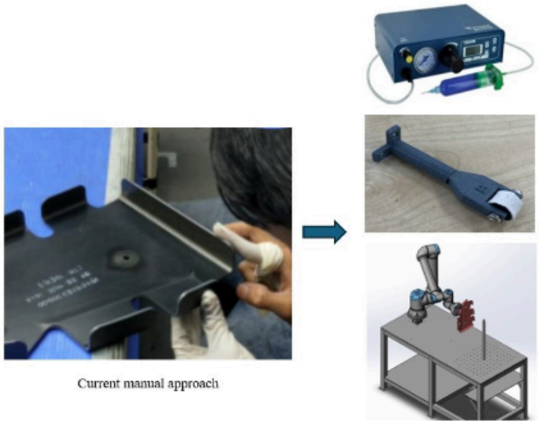
Graphical abstract



Current manual approach

Automation system approach

Abstract

Automating assembly lines in aircraft manufacturing poses significant challenges, entailing both technological complexities and financial risks. A key technical hurdle lies in the precise application of sealant to the aircraft rib panel wing's edge surfaces, which proves to be one of the most intricate operations in the automated manufacturing process due to the complex spatial shapes involved. In this context, the adoption of human-robot collaboration emerges as a viable approach to achieve the necessary customization and adaptability in automation. The fundamental idea is to enhance process efficiency and elevate product quality by employing a sensitive robot to support workers in the manufacturing process. The study has primarily focused on incorporating three distinct mechanisms - a dispensing mechanism, a nozzle applicator, and a robotic arm with a workstation - as essential components of the hardware. These mechanisms play a pivotal role in the successful implementation of the automated robotic sealing system. During the development phase, the system underwent rigorous testing to establish the critical parameters required for the automated robotic sealing process. Results from the study show the ideal pressure range for the dispensing system lies between 2.0 and 3.5 bar. For the nozzle applicator system, the most efficient approach involves extending the base of the 4 mm short straight roller and incorporating a makeup puff. The findings have demonstrated the method and parameters used to achieve optimal results for aircraft components using the automated sealing system process.

Keywords: automated sealing system, dispensing system, nozzle applicator, aircraft components, rib panel

1.0 INTRODUCTION

In the aerospace industry, the rib panel used to develop aircraft wings is made using CNC cutting process. The post-CNC process causes exposure to the edge of the rib panel towards the environment and humans, thus needed a sealing process to cover the exposed edge using dedicated sealant material. However, the method used for the sealing process is manually performed by the human force that uses the finger due to the different shapes and complexity of the rib panel [1]. The automated robot system used for this process is still underdeveloped, as it is challenging to produce the trajectory path for sealing the edge of the rib panel. To address the issue, an automated sealant dispensing system must be implemented for the sealing process to work optimally in the industry. The system is expected to replace the manual application and reduce the process cycle time and material wastage.

Thus, several factors need to be considered before developing automatic robotic sealing system. The first crucial factor is the presentation and classification aspect of the robot. The robot must be able to adjust to the consistent geometry shape of the parts during presentation to ensure proper alignment [2]. Additionally, it needs to maintain sufficient stability and avoid unnecessary alignment steps, which are essential for efficient and effective operations [1]. The efficiency of the sealing robot depends on the number of different parts it needs to handle [3]. When dealing with various sizes and complexities of rib edge panels, the robot's sealing approach must adapt to these differences, making the task less repetitive compared to working on identical rib panel sizes. Robots excel in efficiency when the job is repetitive, such as in pick and place processes. However, handling hundreds of different parts can reduce their overall effectiveness in comparison to handling only a few repetitive parts. The third factor affecting robotic sealing automation is the sizes and shapes of the aircraft components [2]. The problem arises when the part sealed is too big or too small. More significant features might need a different track system for the robot to move to reach all areas. Meanwhile, for smaller components, it might be challenging to get the small areas of the components. Plus, the small part could also be more effective to seal by hand than the robot [4]. Lastly, quality control factors play a role in developing sealing robots [2]. Robots are incapable of detecting consistency, hence they require a complex vision system to take the place of the human eye.

The sealants used, known as epoxy adhesives with high viscosity characteristics, are challenging to handle and must be mixed shortly before the application on the edges of aircraft components. The two parts of epoxy adhesives that need to be integrated are ‘base’ and ‘accelerator’. The base is a modified epoxy in white color meanwhile the accelerator is a modified amine in gray color. Furthermore, mixing ratio requirements are needed between the adhesives are 5:7 parts by weight and 2:3 parts by volume for both base and accelerator, respectively [5]. The sealant cannot contain any contamination and must meet the given ratio specification to ensure the epoxy meets the standards aligned with the aerospace industry. The challenge faced here is that the mixed epoxy adhesives have a working life period, which will be hardened and cannot be used beyond 90 minutes [5]. Thus, it is complex and troublesome as it causes wastage of equipment if both base and accelerator are overly mixed. In this project, a complete system comprising three subsystems will be integrated: the robotic arm with a workstation, dispensing system, and nozzle sealant applicator.

The methodology involves integrating dispensing mechanism, foam, and nozzle applicator modules to create an automatic aircraft sealing system. Optimization of the dispensing mechanism includes CAD design for adapters and precise epoxy dispensing controlled by a pneumatic system and digital signals from the robot. Foam and nozzle applicator components are meticulously designed and tested, with makeup puff foam chosen for superior performance. Multiple designs are developed for the nozzle applicator for precise sealing of aircraft components, aiming for efficient and effective sealing overall.

2.0 METHODOLOGY

2.1 Dispensing Mechanism

Experimental work and analysis have been carried out to improve the amount of air pressure used and the appearance of epoxy on the composite plate. The objective of the experiment is to obtain the optimal pressure that can be used for the dispensing mechanism setup. Figure 1 shows the setup used for undergoing the varying pressure experiment.

The aluminium profile has been used to hold both the syringes filled with base and accelerator. The holder that holds the syringes and the adapter that connects the y-adapter and static mixer are 3D printed. The air pressure issued in the accelerator tube will be constant while the pressure distribution in the base tube will vary starting from 2 bar until 4 bar as shown in Table 1.

Figure 1 Varying pressure experimental setup

Table 1 Parameters for varying pressure analysis

Varying Pressure Analysis (VP)		
Parameters/Analysis	VP-1	VP-2
Syringe diameter	22.3 mm	
Tube internal diameter	4 mm	
Tube length	100 mm	
Pressure of accelerator and base	1bar/0.1MPa (acc), 2-4bar (base)	2bar/0.2MPa (acc), 2-4bar (base)

2.2 Nozzle Applicator Selection

Foam has been chosen as the nozzle applicator tip. There are about seven different materials used for the foam testing. The base and accelerator is mixed using the weight ratio of 5:7, respectively, and become the sealant epoxy to be applied on top of the foam. Among the foams used for the experimental setup are: 1) Makeup puff; 2) Black sponge; 3) Scotch Brite sponge; 4) Green scrubber; 5) Magic sponge; 6) Dishwashing sponge; 7) Bath sponge.

For the size of the foam, all of them have been cut in the same size with an inner diameter of 6 mm and an outer diameter of 14 mm, as depicted in Figure 2. The method is manually performed, where every foam is rolled by hand 90° directly on the paper surface as shown in Figure 3.

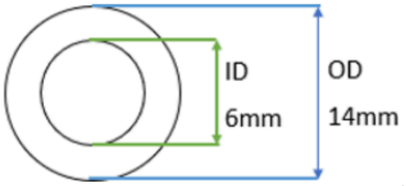


Figure 2 The foam size

Figure 3 Application method of the foam

2.3 Roller Applicator Selection

The selection of the roller applicator is determined by varying the roller height and roller type.

2.3.1 Height of Roller

The objective of this test is to control the force exerted on the foam, as the previous manual hand approach might have inconsistencies with the same force used while pressing the foam on top of the surface paper. Thus, the roller is redesigned using a different height of h = 3mm, 4mm, 5mm, 6mm and 7mm, as shown in Figure 4.

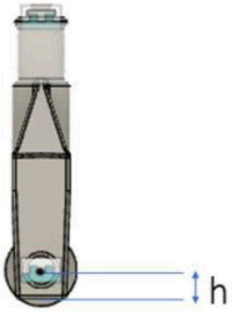
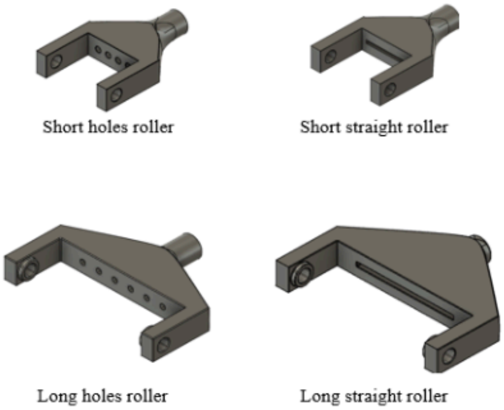


Figure 4 The height difference of the roller

2.3.1 Type of Roller

The next findings are varied by using several different roller types, where four types of rollers with height, h=4mm, 5mm and 6mm have been designed as depicted in Figure 5.


Short holes roller Short straight roller

Long holes roller Long straight roller

Figure 5 Varied rollers by length and hole type

The method used for trying out this approach has been set up as shown in Figure 6. The paper will be pulled below the foam when the dispensing system is dispensed.

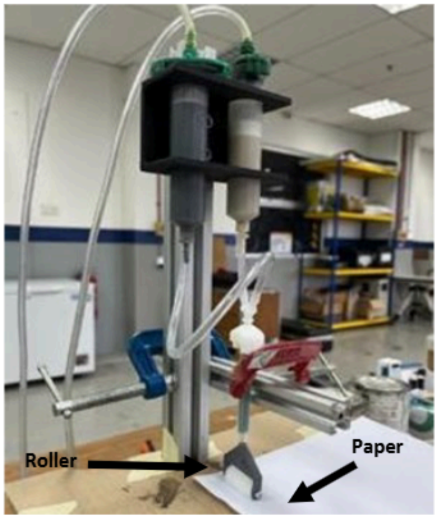


Figure 6 The experimental setup for rollers varied by height and types

3.0 RESULTS

3.1 Dispensing Mechanism

The results data of percentage error on pressure from VP-1 and VP-2 is calculated and plotted in Figure 7(i) and 7(ii).

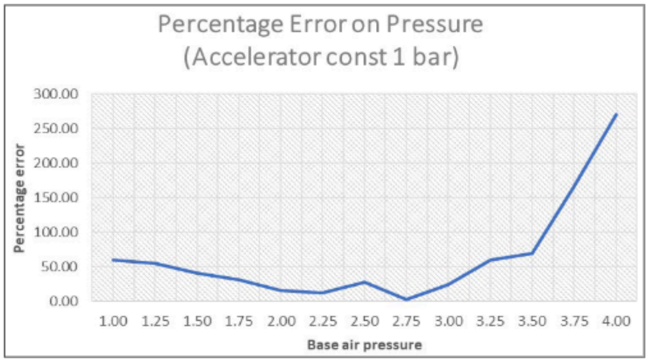


Figure 7(i) VP-1

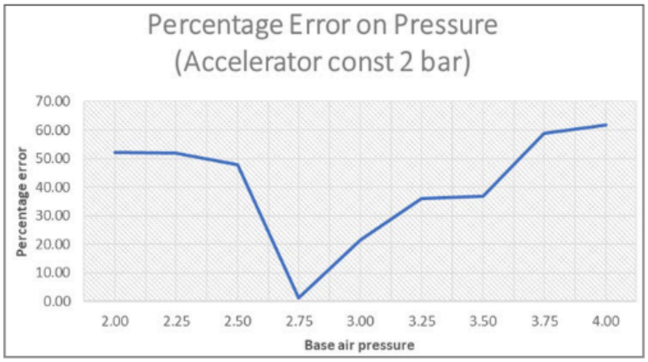


Figure 7(ii) VP-2

Figure 7 Percentage error graphs of VP-1 and VP-2

In Figure 7, the x-axis portrays the base air pressure, while the y-axis conveys the percentage error observed during the experiment. Based on the data presented above, it is evident that the results for VP-1 and VP-2 exhibit inconsistencies. Notably, there is an outlier in the VP-2 results, specifically at a pressure level of 2.75, which deviates significantly from the other data points. Thus, it can be concluded that the dispensed air pressure into the tubes is unstable. There may be some error while controlling the pressure of the base using the pressure regulator that causes the distributed air pressure to be inconsistent. Besides, the error in results can be driven by the presence of bubbles inside the base and the accelerator tubes. Hence, a correct method of transferring the sealant must be followed to avoid bubbling. The syringe that the base or the accelerator will fill must be held at 45° to ensure there is no bubble trap inside the syringe. Before starting the analysis, a proper procedure must be followed to avoid a high error percentage.

3.2 Foam Selection

The results of the foam material application can be seen in Figure 8, in which all seven foams have been ranked based on their appearance results [6]. The method used for deciding the best foam is using visual inspection.

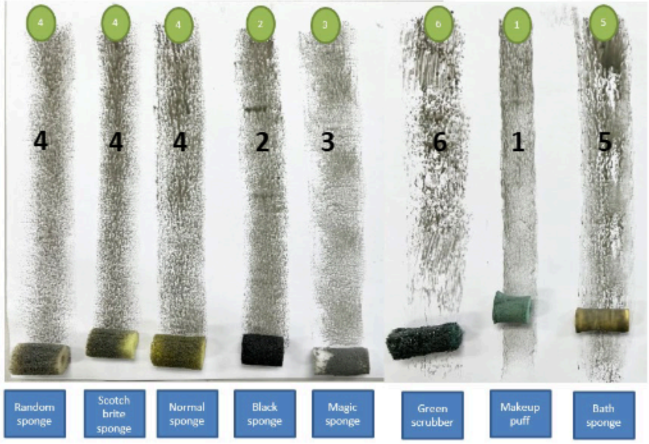


Figure 8 The foam ranking based on visual inspection

Based on the result shown in Figure 8, the top three best foams, that are magic sponge, black sponge and makeup puff have been selected to proceed with the following tests which combined with the designated nozzle applicator.

3.3 Roller Applicator Selection

3.3.1 Height of Roller

The results for the foam tested out using different roller heights varied by length are shown in Figure 9.

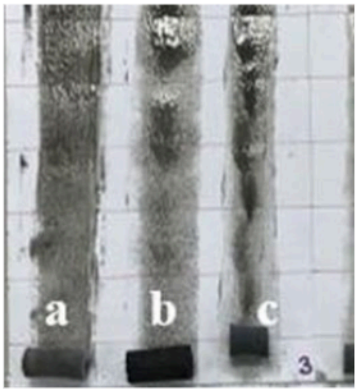


Figure 9(i) Roller height, h=3mm

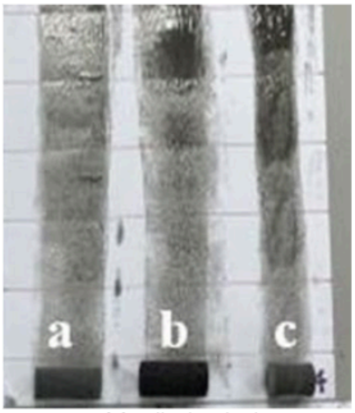


Figure 9(ii) Roller height, h=4mm

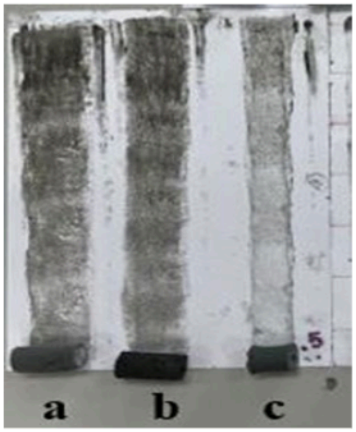


Figure 9(iii) Roller height, h=5mm

Figure 9(iv) Roller height, h=6mm

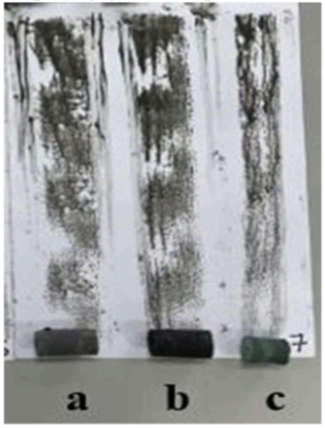


Figure 9(v) Roller height, h=7mm

Figure 9 Results for different roller heights used
(a= Magic sponge, b= Black sponge; c= Makeup puff)

Upon a visual inspection depicted in Figure 9, it becomes apparent that the makeup puff outperforms the other options when considering the thickness and appearance of the epoxy on the paper surface. The variation of height for the roller shows that h = 3mm, 4mm and 5 mm give promising results compared to roller with h = 6mm and 7 mm. However, the observation gained from the experiment indicates that epoxy is dispensed too much from the roller hole, causing the epoxy to overflow and waste the material.

3.3.2 Type of Roller

By employing various types of rollers, as illustrated in Figure 5, it was determined that the short straight roller consistently produces the most desirable finishing outcome. Figure 10 provides a visual representation of the results obtained from experiments involving the rolling of epoxy using makeup puff, black sponge, and magic sponge, all with rollers set at a height of h=3mm, 4mm and 5mm, specifically utilizing the short straight roller type.

Figure 10(i) Roller height, h=3mm

Figure 10(ii) Roller height, h=4mm

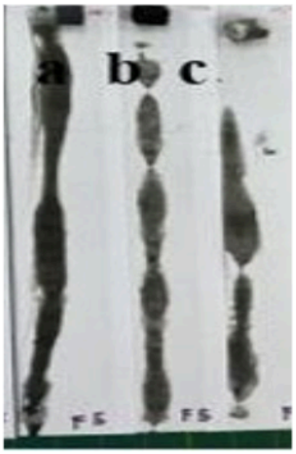


Figure 10(iii) Roller height, h=5mm

Figure 10 Results on rollers varied by height using short straight roller
(a= Makeup puff, b= Black sponge; c= Magic sponge)

Upon visual inspection, it becomes evident that the use of a makeup puff in conjunction with the short straight roller yields the most favorable results. This combination exhibits minimal dragging and a smooth ability to roll across a paper surface. Thus, the experimental findings conclusively states that the short straight roller, set at a height of 4 mm and paired with a makeup puff, delivers the best outcomes in comparison to the other three roller options.

4.0 CONCLUSION

In conclusion, the presented research shows that the automated robot sealing system is beneficial for sealing the edges of aircraft components. These claims can be backed up by the results obtained. Throughout the research study, various tests have been done to obtain the most optimal parameters for the automated robotic sealing system.

The experimental analysis of the dispensing and nozzle applicator setup has been performed in this project. The data from each experiment were taken and compared. Based on the current findings, the parameters used for the dispensing mechanism and nozzle applicator show the desired requirements of the project.

For the dispensing system, the optimal pressure range falls within 2.0 to 3.5 bar. As for the nozzle applicator system, it has been determined that the elongation of the base of the 4 mm short straight roller, combined with the use of a makeup puff, represents the most effective solution. This makeup puff is characterized by its dimensions, which include a length of 13 mm, an inner diameter of 6 mm, and an outer diameter of 14 mm.

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Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper

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