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Global Trend of Glass Bonding for Appliance Industry Assemblies

Chulsoo Woo, Bin Liang and Jonghyuk Oh

Abstract

Due to the ever-increasing need for production efficiency and reliability as well as cost saving, assembly industries have been looking for a better solution compared to current methodologies. It is critically important to know that there is a solution this industry had not paid much attention and can benefit a lot due to not only historical reason but also limited knowledge management or awareness. This chapter examines and qualifies the effect of a couple of special adhesive bonding solutions on various glass plate bonding applications at appliance industry using a total solution such as dispensing system and robot. The result clearly shows its benefit over current methodologies, and also as industry trend moves toward more exterior decoration for high-end image products, this chapter should contribute on glass bonding industry not only for faster production, better efficiency, less production space, and better reliability but also for lower manufacturing cost using special adhesive bonding solutions.

Keywords: decorative glass, bonding strength, polyurethane hot melt, 2 component silicone

1. Introduction

Ever since the appliance industry started its debut a several decades ago, appliances have evolved through various changes of performance both with their original functions and energy consumption and better high-end appearance while other parameters have come to almost achievable limit, the demand for diverse functions and appearance images that still draw hearts of multiple consumers. Now appliances have been inevitable items for every house for its convenience yet and improvement of life.

As customer's interests for high-end image products are ever increasing, and more simplified manufacturing processes with a high quality at lower cost have to be met, assembly industries have been looking for various solutions. In the beginning, they have adopted various mechanical assembly methods, one of which has been a tape method. For example, the front side design of previous major home appliances has been plastic, painted metal, or printed film on top of bare metal frame. It was difficult to achieve a high-end image with such simple design. With the use of printed glass plate, the whole image of appliances has been upgraded and met the demands of consumers who aspired better appearance of appliances; it has given more freedom to make diverse front images using all different printings at the



Figure 1.
Glass bonding for refrigerator and side view.



Figure 2.
Glass bonding for top loading washing machine.



Figure 3.
Glass bonding for front door of microwave.

back side of glass plate. A few examples can be shown in **Figures 1–8**. The latest solution was a special structural adhesive that is cured by a chemical reaction. In this chapter, we would like to introduce two structural adhesive technologies, such as polyurethane hot melt technology and 2 component silicone technology, evaluate their performance and compare and analyze its difference from the current tape solution and 1 component silicone + tape solution and mechanical way on process efficiency, reliability as well as cost saving. Those appliances (or white goods) have been used at almost all the housings, and those appliances that have adopted glass plate bonding are refrigerator, washing machine, microwave, cook top, air



Figure 4.
Glass bonding of ceramic glass for microwave.



Figure 5.
Glass bonding for wall type air conditioner.



Figure 6.
Glass bonding for stand-alone type dish washer.

conditioner, dish washer, kitchen ventilation hood, styler, etc. Each appliance is explained further on the area of glass plate bonding applications. In the literature, there is only a few research on glass bonding with conventional methods, but there is not any research on glass bonding with adhesives which we focused on in this report. In this study, double-sided tape and actual test substrates were received from appliance customers, and PUR hot melt and 2C silicone adhesives were received from Henkel laboratory.



Figure 7.
Glass bonding for kitchen ventilation hood.



Figure 8.
Glass bonding for styler.

2. Major appliances

Those requiring glass bonding are described as follows.

2.1 Refrigerator

Refrigerator is one of the items that can adopt glass bonding applications for various and different designs in terms of shape and function such as one door, two door, triple door, double door, French door, chest type, upright type, freezer, and kimchi refrigerator. They all can adopt glass plate bonding applications such as all front doors, inclined area between double and two triple doors, and water dispenser area on a front door and control panel. The most popular glass bonding application is a front glass plate bonding to the plastic door chassis. The below **Figure 1** shows a glass plate bonded to front door and a glass plate bonded from side view [1].

2.2 Washing machine

Washing machine has a few application areas that can adopt glass plate bonding applications in terms of shape and function such as top loading, front loading, and combined top and front loading, and they all can adopt a printed glass plate bonding application including control panel area. The most popular application is a glass bonding of top cover to plastic cover frame for top loading washing machine. Front loading type has a door assembled with glass and plastic frame by screws. This structure can be assembled by using a special structural adhesive eliminating screws and its related extra process to use screws. The combined front loading (on top) and top loading (on the bottom) has a function of washing clothe at the same time. The top loading type washing machine in the bottom part slides out front and do the washing. Other application is for bonding of a glass door frame to a glass door for the function of opening and throwing in a forgotten laundry while the washing machine is already running. The below **Figure 2** shows a glass bonding of top cover to plastic frame for top loading washing machine [2].

2.3 Microwave

Microwave has a few glass plate bonding applications. The most popular application is for bonding of front glass plate to outside front plastic door. Other applications are for bonding of glass plate to inner front metal door frame. One more application for a high-end microwave is for bonding of glass plate to bottom body frame. The below **Figure 3** shows a front door glass bonding to plastic door frame [3].

2.4 Cook top

Cook top uses an electrical coil with ceramic glass placed on top where they put pots and pans to cook food instead of using gas. The coil generates heat that transfer through a ceramic glass to food. It is a much more high-end image with a sleek design for easier cleaning and better health, and it has a safety advantage during cooking as people can wipe out contamination easily and do not need to inhale the burning gas. The most popular application is for bonding of ceramic glass to ceramic-coated metal frame. Other application is for bonding of ceramic glass to inner metal chassis. The below **Figure 4** shows a ceramic glass that is bonded to metal ceramic coating surface and to metal chassis [3].

2.5 Air conditioner

Air conditioner has a different type of design that can adopt glass plate bonding in terms of shape and function such as window type, wall type, standalone vertical type, and ceiling type. The most popular application is for bonding of a glass plate to plastic frame for wall type air conditioner. This type of application needs a reliable bonding solution as the glass might fall off from air conditioner and cause a safety problem for people if an improper solution is used. The below **Figure 5** shows a glass bonding to plastic frame of wall type air conditioner [4].

2.6 Dish washer

Dish washer has a different type in terms of shape and function that can use a glass bonding application such as table top, built in stand-alone type, and drawer type that can adopt glass bonding application in the front side. The most popular application is for bonding of glass plate to plastic front door for stand-alone type. The below **Figure 6** shows a glass bonding for stand-alone type washing machine [5].

2.7 Kitchen ventilation hood

Kitchen ventilation hood can have three glass plate bonding application for its function of easy cleaning of contamination from cooking and high-end image and appearance. This type of design has the glass plate in the middle which is in a closed state. When it is turned on, the glass plate in the middle opens up and the fan inside sucks those fumes, smokes, and microparticles generated during cooking. For a situation where the glass plate is contaminated with oil due to splash of boiling oil during cooking, it can be wiped off easily for clean surface. The most popular application is for bonding of glass plate to moving chassis. Other applications are for bonding of glass to control panel chassis and bonding of glass to other chassis. The below **Figure 7** shows an overall glass bonding area of kitchen ventilation hood.

2.8 Styler

Styler has a glass plate bonding application such as bonding of glass plate to plastic frame on the front side of it. It is a stand-alone type and has a function of eliminating dust by vibrating the clothe, deodorization by vacuum fan, sterilization by steam heating, and ironing of the clothe by heat pressing overnight inside it and next day they can take it out of the styler and put it on. The below **Figure 8** shows a glass bonding in front of styler.

3. Assembly solutions

In this section, we are going to list up and review major solutions that have been used in the industry and new solutions that can be used in this industry. Conventional methods consist of mainly double-sided tape, 1 component silicone, and mechanical fasteners, and new special adhesive solutions are polyurethane hot melt technology and 2 component silicone technology. We will review characteristics of each solution.

3.1 Double-sided tape

This technology has been used widely in the assembly industry. It has had a wide range of awareness in the market place. It can fix the parts within 1 min and no

chemical reaction is required. But at the same time, it requires a high labor-intensive pre-work such as priming the surface with a primer to improve a bonding durability. It also requires a peel-off of release paper on one side and place the sticky part on the application area mostly manually. It is very difficult to re-adjust the location once it is placed on the substrate, and very high labor cost is required if it has to be re-adjusted. It has to be pressed for a certain amount of time; otherwise, there is no good affinity achieved between the sticky surface of tape and the substrate. The de-bonding happens when bonding a surface not completely flat. Tape solution also generates a bulky waste of release paper. Tape solution tends to release the bonding property under aging condition; therefore, a gap is generated in the glass bonding area as time goes causing a repair. The adhesion of tape is the surface temperature dependent; therefore, if the temperature of assembly line, tape, and substrate was not properly controlled, especially in the winter time due to the effect of cold temperature on the bonding durability of tape, it generates a poor adhesion to substrate and consequently a bonding failure, scrap, and liability issue [6].

3.2 Mechanical fastener

This technology has been available with a history of mankind for a very long time. This can provide a very fast mechanical fixture and consequent assembly, but at the same time, this requires mechanical fasteners and drilled thread holes on both parts, and operator has to assemble them by using fastening tools manually. The assembly leaves a screw mark that is not good in appearance and it is also difficult to make an automation assembly line, too [7].

3.3 1 component RTV silicone

This technology is a room temperature vulcanized (RTV) silicone that reacts with moisture in the air and substrate, and generates some by-products such as oxime, alcohol, acetic acid, and acetone. This technology in general has a high viscosity with a slow curing property that takes a few days for functional bonding and more than 1 week for a complete curing. Normally this technology requires mechanical clips or double-sided tapes for initial fixture time and a stacking space and lengthy curing time before it goes to the next process. Some process adopts 1 component RTV silicone or double-sided tape which requires more manual process and manpower cost [8].

3.4 Polyurethane hot melt

This technology is at first a thermoplastic (remeltable) material that contains some free isocyanate groups, and then, it is similar with 1 component polyurethane technology that reacts with moisture to form a tough thermoset (not meltable) plastic material. Its initial thermoplastic property can melt easily and provide a very excellent high position tack capability that can hold the two substrates in place by losing an energy from molten liquid state, and also its thermoset property provides a high temperature heat and creep resistance with a good durability. Polyurethane hot melt is available with a wide range of open time. This technology has a good adhesion and is compatible with a wide variety of substrates. It has better bonding strength performance and environment resistance compared to normal hot melt due its cross-linked chemical reaction property. It has a relatively lower operation temperature around 120°C; therefore, a dispensing at lower energy is possible. It also has longer open time 1–4 min; therefore, it has a wide bonding window for

assembly. This technology is just like other 1 component and 2 component polyurethane adhesives, and during the reaction, generates some carbon dioxide (CO₂) to evaporate.

Additional characteristics are excellent toughness, flexibility, high elongation, excellent gap filling, paintable when cured, and excellent chemical resistance.

As shown in **Figure 9**, isocyanate NCO reacts with moisture in air and substrate and becomes an oligomer with by-product carbon dioxide evaporating; then, these oligomers react each other to form a cured polyurethane [9].

As shown in **Figure 10**, polyurethane hot melt is in a solid state in the sealed aluminum foil packaging to prevent the ingress of moisture in the solid product that can react to become a thermoset plastic. After the product becomes a molten state at elevated temperature by melting machine, it is dispensed onto the substrate, and substrates are mated at “a: joining time”, as it loses the energy, and it solidifies just

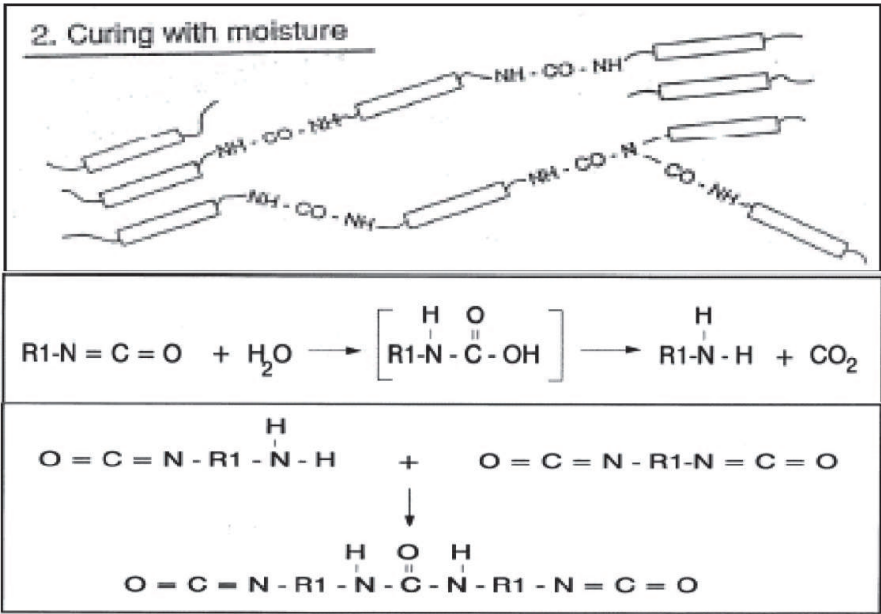


Figure 9.
PUR HM curing mechanism with moisture.

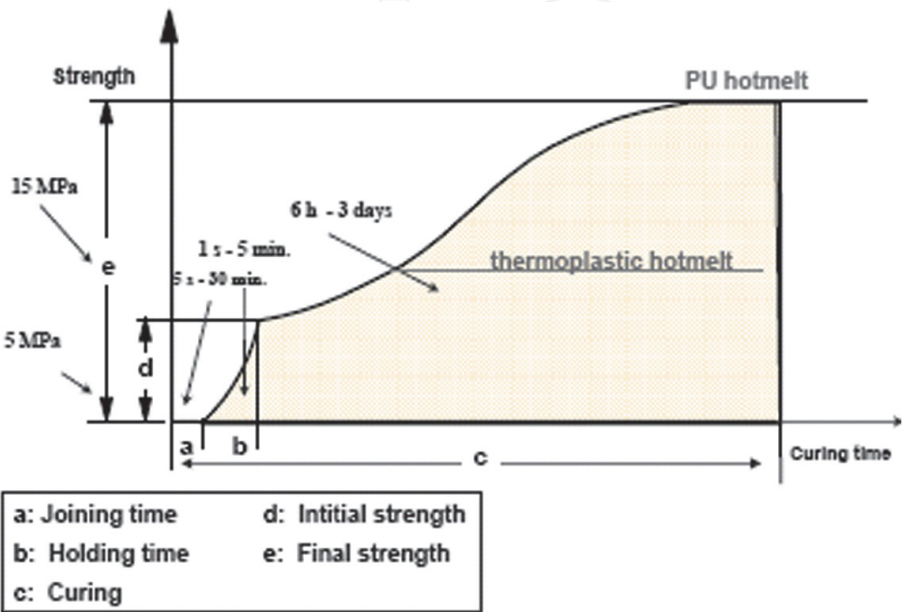


Figure 10.
PUR HM curing strength vs. curing time.

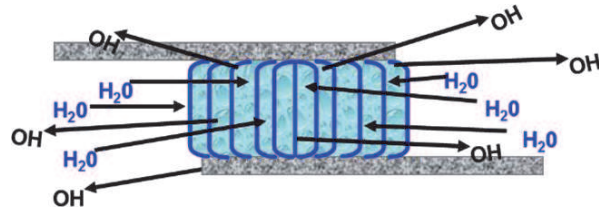


Figure 11.
 2C silicone curing mechanism.

like normal hot melt and starts to build an initial bonding strength “d” at “b: holding time.” Once it solidifies by losing energy, it starts to react with moisture and cures chemically to form a much higher bonding strength at “curing time c” and finally comes to a final bonding strength “e.” Therefore, a very fast fixturing and reliable bonding can be achieved with this technology. Polyurethane hot melt is dispensed by melting machine and robot or by roll coating machine; in this chapter, for glass bonding application, melting machine and robot are used mostly [9].

3.5 2 component silicone

When part A and part B are mixed in a proper mixing ratio, a chemical reaction occurs which is initiated by the catalyst reacting with water. This chemical reaction occurs not only at the surface but also inside the mixed product. Therefore, it has a very fast fixturing and curing time for faster fixture and assembly, and it allows a structural bonding assembly in more compact assembly line and automated assembly with less manpower. This technology can replace various assemblies that have used double-sided tape or RTV silicone that requires a manual and lengthy assembly line and time with much manpower. During the chemical reaction, moisture (“H₂O”) comes in and alcohol (“OH”) that was generated during chemical reaction as a by-product comes out and evaporates (see **Figure 11**) [8].

Two-component silicone characteristics are fast tack free, fixture and curing time, and cure speed not affected by moisture, and cure speed less affected by bond line thickness, and excellent thermal resistance (“up to 270°C”), and flexible, tough, high modulus, and agency UL 746°C listed for high temperature applications for appliance, and excellent gap filling, and black, gray and almond colors are available [8].

4. Refrigerator

First of all, in this section, we are going to compare polyurethane hot melt adhesive solution vs. tape solution based on parameters such as assembly process, environment reliability, tensile shear strength against open time, cross pull strength against fixture time, design benefit, air pockets on bond line, bond line thickness, creep resistance, dispensing equipment, and overall value analysis. The application is for bonding of glass to plastic frame for various refrigerator doors [1].

4.1 Assembly process

Tape solution is to apply primer to plastic frame by 1 worker (5 s) → apply tape to plastic frame and cut manually by 2 workers (20–40 s) → peel off release paper manually by 2 workers (5 s) → place glass plate onto the plastic frame manually by 1 worker (10 s) → compress the glass plate by pressing (5–10 s) → next process. This solution takes a total of 4 workers and 70 s.

Polyurethane hot melt adhesive solution is to apply adhesive to plastic frame by machine (10 s) → place glass plate onto the plastic frame manually by 1 worker or by machine (0–10 s) → compress glass plate by pressing (5–10 s) → next process.

This polyurethane hot melt adhesive solution takes only a total of 1 or no workers and 30 s, which means it requires almost no worker and a half process time compared to tape solution. This adhesive bonding solution can save 5 or 6 workers and can use them in other more important work places, can save overall assembly time in half, and can reduce assembly line space more compact and eliminate waste coming from release paper from tape solution. Tape solution requires a primer process for more reliable bonding as its adhesion decreases when the ambient temperature was relatively low; then, the complete wetting of tape onto the substrate was not fully established resulting in bonding reliability issue down the road, while adhesive bonding solution wets all the mating surfaces and penetrates all the surface imperfections and mechanically grip the surface after cure contributing more reliable bonding, and also much reduced process steps allow more reduction of quality check points, too [1].

4.2 Tensile shear strength vs. aging conditions

Testing has been carried out to measure a tensile shear strength to compare the bonding reliability before and after aging condition between adhesive solution and tape solution. Substrate was a high temperature ink printed glass and a plastic combined with PC and ABS. Testing conditions were at room temperature (23°C), low temperature (−40°C for 7 days), high temperature (80°C for 7 days), high temperature, and high humidity (50°C, 95%RH for 8 h, 5°C 95%RH for 8 h as 1 cycle for 1000 h) and thermal cycle tests (60°C for 4 h to −30°C for 4 h as 1 cycle for 1000 h). As shown in **Figure 12**, adhesive solution has at least 10 times higher bonding strength for all aging conditions. It was shown that both adhesive and tape have increased their bonding strength a bit, but adhesive solution still has maintained at least 10 times higher bonding strength than the tape solution. If we review the thermal cycle test, strength has increased for adhesive solution, but it has decreased for tape; consequently, adhesive solution has 13 times of higher bonding strength than the tape solution. Overall, it is very clear that as far as environmental durability is concerned, adhesive solution provides a far more reliable bonding than the tape solution.

4.3 Tensile shear strength vs. open time

Testing has been conducted to measure a tensile shear strength per different open time which means the time after adhesive dispensing until mating the other

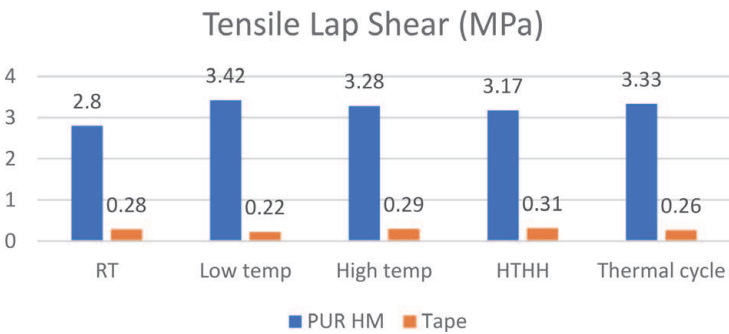


Figure 12.
Tensile shear strength vs. different aging conditions.

substrate. A variation of tensile shear strength between adhesive and tape was checked and compared in **Figure 13**. As it is shown below, adhesive solution has 10 times of higher bonding strength than the tape solution from open time of 15–30 s to 2 min; and the adhesive solution still maintains 7–8 times of higher tensile shear strength than the tape solution from open time of 4 min to max 15 min. It explains that adhesive solution has a lot of assembly process freedom as same as tape solution, yet it achieves a much higher and reliable bonding strength. The realistic handling time that manufacturer allows is within 2 min after adhesive dispensing as the assemblies need to move to the next station as early as possible. Therefore, the quality of bonding strength with adhesive solution can be achieved in most appliance assembly process conditions.

Tape solution maintains the same level of tensile shear strength but in a much lower figure.

4.4 Cross pull strength vs. fixture time

Testing has been carried out to measure an initial fixture strength per holding time between adhesive and tape solution. An initial fixture time means a bonding strength developed after dispensing and assembly. As shown in the below **Figure 14**, tape solution shows a higher initial fixture strength at 1 min holding time; however, as time goes by adhesive solution achieves higher strength than tape, and as time goes further, adhesive solution reacts with moisture. The holding time in **Figure 14** is the one adhesive solution that still maintains a solidified hot melt status which is not chemically reacted, yet shows higher strength after 2 min of holding time. As time goes further, the adhesive reacts with moisture and achieves a chemically reacted bonding strength which is at least 10 times higher than the tape solution as seen in **Figure 12**. The holding time of less than 2 min is not realistic condition as most of manufacturers use more than 2 min of holding time due to handling other parts until the next process. The substrate tested was glass bonded to combined PC and ABS.

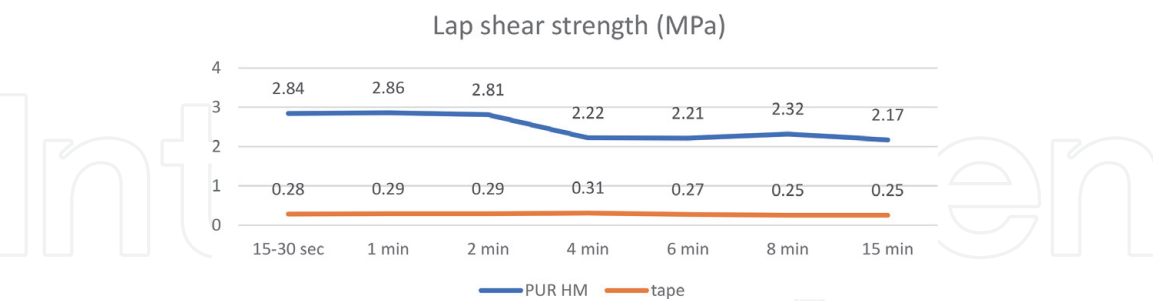


Figure 13.
Tensile shear strength vs. open time.

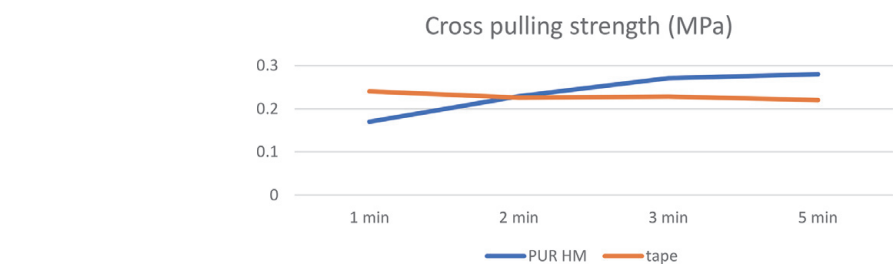


Figure 14.
Cross pull strength vs. fixture time.

4.5 Better design vs. design complexity

Tape solution has a certain thickness (1 mm) of tape and once it is pressed, it becomes to 0.8 mm thickness. When adopting the glass plate bonding design, its own tape thickness puts some limitations on the freedom of design and causes additional unnecessary and complicated design and assembly process due to its design. For instance, 0.8 mm of gap between glass pate and body frame is clearly and easily visible to the eyes of consumers as the application of glass bonding is always external and it affects the image of their product on consumer’s preference and expectation on high-end image appliances. Manufacturers who used a tape solution have adopted additional side frame to cover the gap and not to let consumers realize that there was a gap clearly visible, or designed a special threshold on the outer end of body frame so that the gap is not visible outside from the eyes of consumer as shown in **Figure 15**; ultimately, it has caused more cost, more process complexity, and more manpower as well as poor high-end image as it is clearly and vividly different if they compare the image of refrigerator between the one that has a side cover on the glass (with tape solution) and the one that has no side cover, just bonding of glass plate to body frame (with adhesive solution).

4.6 Air pockets on the bondline

Tape solution has an inheritable structural limitation to achieve a complete contact to substrate as it is a solid form, and taping/pressing is also done manually. **Figures 16** and **17** show an actual application with tape for refrigerator; as shown in figures, many area of tape has detached area causing a low bonding strength and durability, and especially in the high-temperature, high-humidity aging condition, the bonding reliability decreases as the detached area is expanding due to temperature increase and moisture ingress over time. In general, the air pockets in the tape solution on the bondline are quite substantial such as 40–50% in some worst cases as the substrate surface is not always flat. On the other hand, the adhesive solution can prevent such air pocket possibilities as it is a liquid and it flows and fills all the

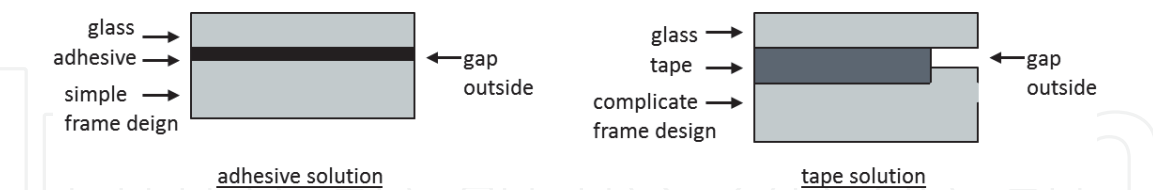


Figure 15. Gap and design complexity between tape and adhesive.

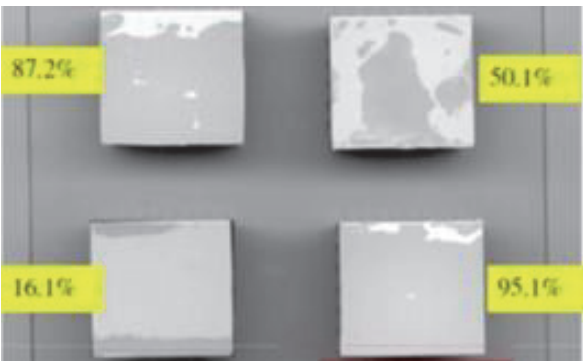


Figure 16. Air pocket for tape.

surface imperfections, meaning no air pocket, and provides a tough bonding resulting in better reliability and durability than the tape solution.

4.7 Bondline vs. environment condition

Tape solution when subjected to various environment conditions increases its thickness by expanding, due to high temperature and moisture ingress; it increases to 1 mm in some cases. The adhesive solution maintains quite consistently in terms of its thickness before and after various environment conditions. In case of high-temperature condition (80°C for 7 days), the delta is average 0.04 mm which is very minimal as shown in **Tables 1–3**. In case of thermal cycle condition (50°C, 95% RH for 8 h to 5°C, 95%RH for 8 h as 1 cycle for 1000 h), the delta is 0.01 mm. In case of bigger range of thermal cycle, (60°C, 95%RH for 16 h to –30°C for 4 h as 1 cycle for 1000 h), the delta is 0.05 mm. The above test results confirm the reliability and excellent environmental resistance of adhesive solution in achieving a durability and ultimately a better quality of appliances.

Figures 18 and 19 explain the gap generated between adhesive solution and tape solution. For adhesive solution, as shown in **Figure 18**, it is very narrow for a coin to penetrate, while for tape solution, as shown in **Figure 19**, there is a gap that is big enough for coin to penetrate.

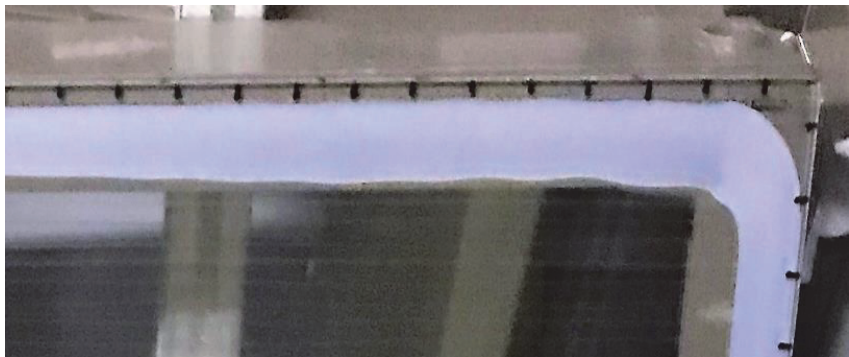


Figure 17.
No air pocket for adhesive.

Point	Before aging	After aging	Δ
1	0.18 mm	0.15 mm	- 0.03 mm
2	0.20 mm	0.15 mm	- 0.05 mm
3	0.50 mm	0.50 mm	0 mm
4	0.30 mm	0.25 mm	- 0.05 mm
5	0.55 mm	0.50 mm	- 0.05 mm
6	0.60 mm	0.54 mm	- 0.06 mm
7	0.45 mm	0.45 mm	0 mm
8	0.15 mm	0.09 mm	- 0.06 mm
9	0.45 mm	0.40 mm	- 0.05 mm
		Avg	- 0.04 mm
		Max	- 0.06 mm

Table 1.
High temperature.

Point	Before aging	After aging	Δ
1	0.18 mm	0.18 mm	0 mm
2	0.02 mm	0 mm	- 0.02 mm
3	0.02 mm	0 mm	- 0.02 mm
4	0.10 mm	0.06 mm	- 0.04 mm
5	0.15 mm	0.14 mm	- 0.01 mm
6	0 mm	0 mm	0 mm
7	0.65 mm	0.66 mm	0.01 mm
8	0.63 mm	0.58 mm	- 0.05 mm
9	0.11 mm	0.10 mm	- 0.01 mm
10	0.03 mm	0 mm	- 0.03 mm
11	0.23 mm	0.23 mm	0 mm
12	0.40 mm	0.40 mm	0 mm
		Avg	- 0.01 mm
		Max	- 0.05 mm

Table 2.
Thermal cycle.

Point	Before aging	After aging	Δ
1	0.33 mm	0.38 mm	0.05 mm
2	0.07 mm	0.18 mm	0.11 mm
3	0.40 mm	0.50 mm	0.10 mm
4	0.47 mm	0.55 mm	0.08 mm
5	0.38 mm	0.45 mm	0.07 mm
6	0.40 mm	0.50 mm	0.10 mm
7	0.25 mm	0.30 mm	0.05 mm
8	0.42 mm	0.45 mm	0.03 mm
9	0.04 mm	0 mm	- 0.04 mm
10	0.20 mm	0.15 mm	- 0.05 mm
11	0.10 mm	0.06 mm	- 0.04 mm
12	0.12 mm	0.15 mm	0.03 mm
13	0.50 mm	0.60 mm	0.10 mm
		Avg	- 0.05 mm
		Max	0.11 mm

Table 3.
Higher thermal cycle.

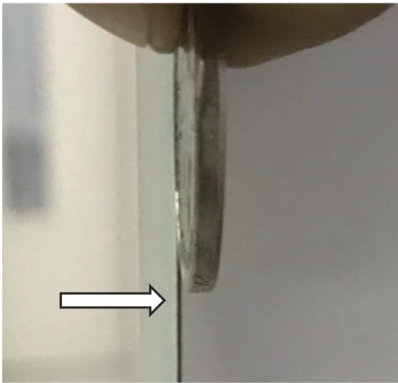


Figure 18.
No gap with adhesive.

4.8 Initial creep resistance vs. load

Testing has been done to measure a creep resistance of adhesive solution after applying onto substrate. The assembly test method was to hang 150 g weight to bonded specimen for max 10 min and measure the creep at each different fixture time. This weight and bond area are representations of actual glass bonding for refrigerator when the bonded assembly is put in upright position after bonding at horizontal position; then the glass, due to its weight and gravity, tends to move downward. The adhesive solution has to grip the glass in place after a certain fixture time at horizontal position. As shown in **Figure 20**, “1 time” means the same weight condition as actual glass load (glass weight/bonding area). “2 times” means 2 times more weight that was used to measure the creep. It has no creep in 5 min of fixture time and this is a severe condition. “5 times” means 5 times more weight that was used to measure the creep. It has no creep in 10 min of fixture time and this is a very severe condition. For “1 min” condition, 5 kg weight has a 2.5 mm creep at 15 s of fixture time, but as fixture time goes further, the creep reduces and at 4 min fixture time after assembly, it has no creep at all. This is the time that customers have and use in their assembly line. Anyway adhesive solution has a good fixture time with 4 mins of bonding after which bonded glass plate is placed vertically in such short amount of time and there is no creep that is adopted by various manufacturers, mostly their time is longer than 4 min. This explains the efficiency and durability of adhesive solution for process consideration when the refrigerator is put in upright position.

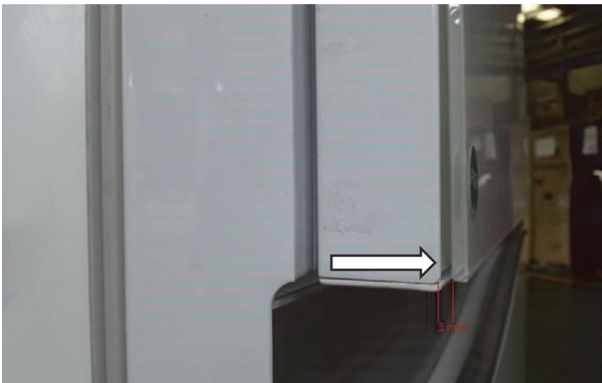


Figure 19.
Gap with tape.

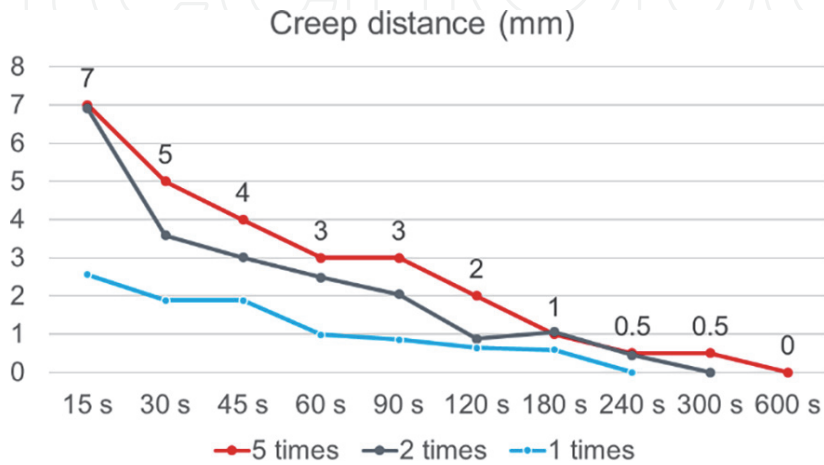


Figure 20.
Initial creep resistance vs. load.



Figure 21.
Overall value analysis per year.

4.9 Automation equipment

While tape solution cannot be automated by using equipment, one of many benefits of adhesive solutions is to automate the assembly line. Adhesive solution in this case requires a melting machine and a robot. Melting machine is required to melt the solid-state adhesive into the molten state. The adhesive is then applied in a liquid state onto substrate and as soon as it touches the substrate, it loses its energy quickly and hardens into solid. Robot is required to position (control) a dispensing area and location; currently, a 6-axis robot is recommended to this application for manufacturers. Typical parameters of melting machine and robot are 10 s of adhesive dispensing for 650 × 750 mm refrigerator door, dispensing speed is 300 mm/s for 15 g/min, pump speed is 103 RPM, application temperature is 130°C, adhesive bead height is 2–2.5 mm, and bead width is 7–11 mm. These allow manufacturers to make the assembly line with less manpower, less space, and better work in process (WIP).

4.10 Overall value analysis

Cost comparison has been done for overall required cost between tape solution and adhesive solution for glass plate bonding for refrigerator door as shown in **Figure 21**.

The cost for tape was 1,100,000 Euro, which is positive value for adhesive solution, meaning the value they can save by using adhesive solution was 798,000 Euro; and additional cost of adhesive solution was 0 Euro. The total prospect value that the manufacturer can save by using adhesive solution was 1,898,000 Euro. The cost for total adhesive solution was 730,000 Euro, which includes adhesive cost 660,000 Euro + equipment cost (melting machine + robot) 210,000 Euro, and 1 year depreciation cost for equipment is 70,000 Euro. Therefore, the adhesive cost becomes 730,000 Euro (660,000 + 70,000). the ultimate value to manufacturer can be 1,168,000 Euro which was calculated based on 1-year production. The capital investment cost for melting machine and 6-axis robot required when using adhesive solution can be calculated and the pay-back time will be 0.4 (730,000/1,898,000) year.

5. Washing machine

In this section, we are going to compare polyurethane hot melt solution vs. 1 component room temperature vulcanizing (RTV) silicone solution for top loading

type that used to use a folding plastic top cover which changed to an ink printed glass cover for better appearance and high-end image as a value sold in the market place. The application area is for bonding of glass plate to ABS plastic frame for top loading washing machine cover [2].

5.1 Assembly process

One-component room temperature vulcanizing solution is to apply silicone onto a plastic frame by dispenser with 3 axis robot that is an assembly of bare ABS and chrome-plated ABS that was assembled by mechanical screws (23 s) → place glass plate on top by 1 operator (2 s) → put several mechanical clamps or wrap the tape around the assembly for fixture by 1 operator (10 s) → transfer it to the rack (3 s) → rack placed in the corner of plant for curing (24 h, space) → move to next assembly process.

Polyurethane hot melt solution is to apply to a plastic frame that is an assembly of bare ABS and chrome-plated ABS that was assembled by mechanical screws by using an automatic dispensing machine as well as dispensing robot (23 s) → place glass plate on top by 1 operator and press for 30 s → assembly is fixtured and then goes to the next assembly process.

Comparing those two solutions, polyurethane hot melt adhesive solution takes a total of 1 or no operator and very compact assembly process time (total 1 min) while existing 1C silicone solution requires 2 workers and complicated and longer assembly process time such as taping 4 corners of cover, clamping or wrapping the assembled parts for curing, and a space for stacked assemblies to cure for 24 h before it moves to the next assembly process [2].

5.2 Initial fixture time vs. loading

Testing has been carried out to measure and compare an initial fixture strength per loading between polyurethane hot melt adhesive solution and 1 component silicone solution. As shown in **Figure 22**, adhesive is applied onto ABS plastic assembly; then, a glass plate is placed on it and pressed for 30 s, and the assembly is conditioned at different interval time, placed upside down; 25 kg weight is placed upon the glass part and then it is observed if the assembled glass remains bonded or falls apart. As shown in **Table 4**, polyurethane hot melt adhesive has no de-bonding even at 1 min curing while 1 component silicone takes a much longer curing time;

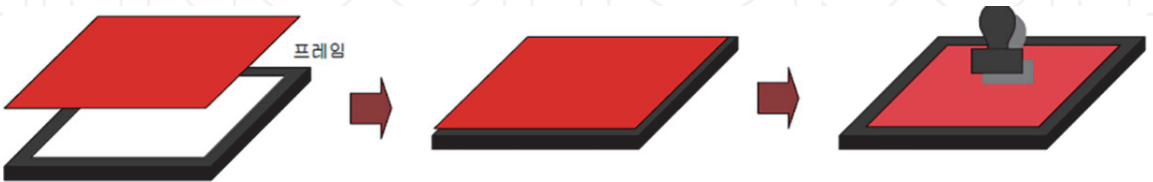


Figure 22.
Fixture time test condition.

Solution	1 min cure	3 min cure	5 min cure	10 min cure
PUR HM	No de-bonding	No de-bonding	No de-bonding	No de-bonding
1C silicone	De-bonding	De-bonding	De-bonding	De-bonding

Table 4.
Fixture time comparison.

therefore, it has a de-bonding even after 10 min of curing time. This explains more compact and process efficient assembly process with less time and less manpower for polyurethane hot melt adhesive compared to 1 component silicone solution.

5.3 Bonding strength vs. environmental condition 1 vs. loading

Testing has been done to measure the bonding strength, failure mode per different loading after a high temperature environmental condition (70°C for 1 week), and a high humidity condition (50°C/95%RH for 1 week). As shown in **Table 5**, polyurethane hot melt adhesive solution has no de-bonding when the weight loading of 25, 50, and 100 kg was placed on top of glass part; then, 3 times of 100 kg impact was applied to the glass part and the bond line remained intact between glass and mating substrates but the glass in the middle was shattered instead. **Figures 23** and **24** explain the intact bond line area of both chrome-plated + glass and ABS + glass bonding.

5.4 Tensile shear strength vs. environmental condition

Testing has been conducted to measure and compare using test specimen the tensile shear strength at different high temperature (85°C) and high humidity (85% RH) for max 1000 h aging time. Specimen was glass and ABS, together with painted ABS substrates. After adhesive dispensing and glass part assembly, it was put into environment chamber immediately. As shown in **Figures 25** and **26**, we can see that as the aging time progresses, the tensile shear strength difference is widened explaining that the PUR HM adhesive increases as time goes by, while 1 component silicone has no curing within 1 h of aging and maintains a lower strength than polyurethane hot melt adhesive; especially for painted ABS substrate, it shows a

Aging condition	25 kg weight	50 kg weight	100 kg weight
70°C × 1 week	No de-bonding	No de-bonding	No de-bonding
50 °C × 95%RH × 1 week	No de-bonding	No de-bonding	No de-bonding

Table 5.
Bonding strength vs. loading.



Figure 23.
Chrome-plated + glass bonding.

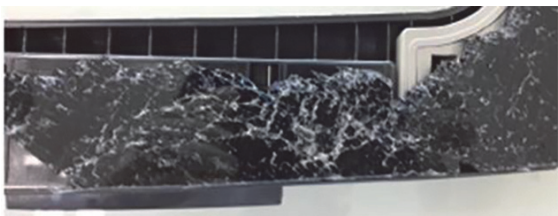


Figure 24.
ABS + glass bonding.

sharp decrease of bonding strength at 1000 h. Polyurethane hot melt adhesive shows an immediate certain strength initially due to pure hot melt fixturing function, but as time goes by, due to the chemical reaction, the adhesion strength increases to a higher reliable level. The assembly of glass to painted ABS shows a higher ultimate strength than the assembly of glass to ABS.

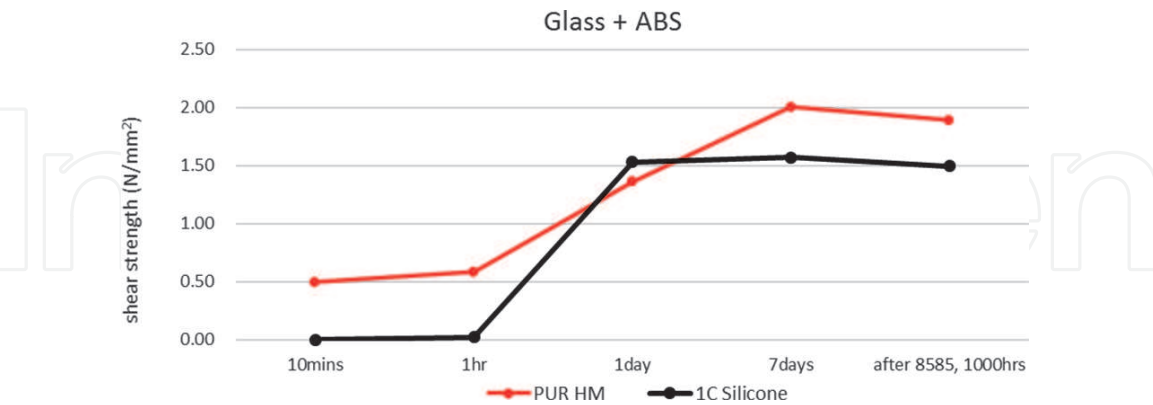


Figure 25.
Tensile shear strength comparison for glass + ABS.

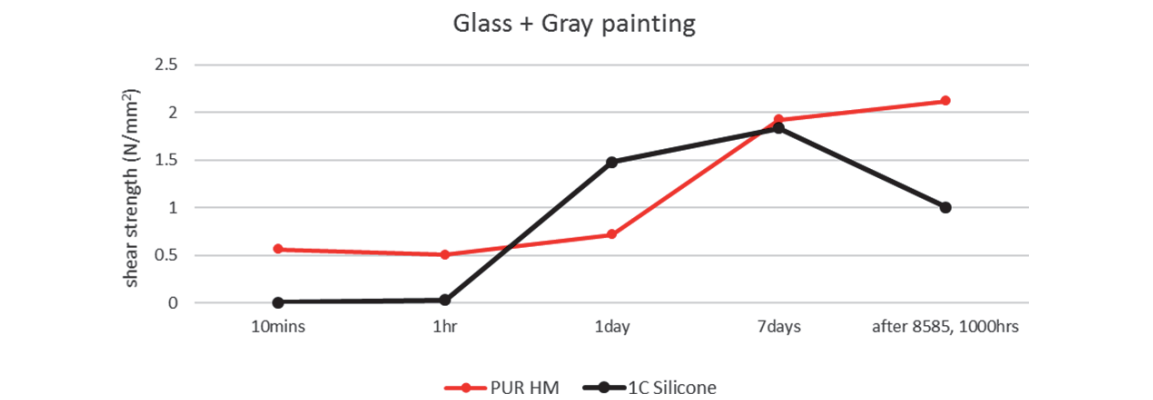


Figure 26.
Tensile shear strength comparison for glass + painted ABS.

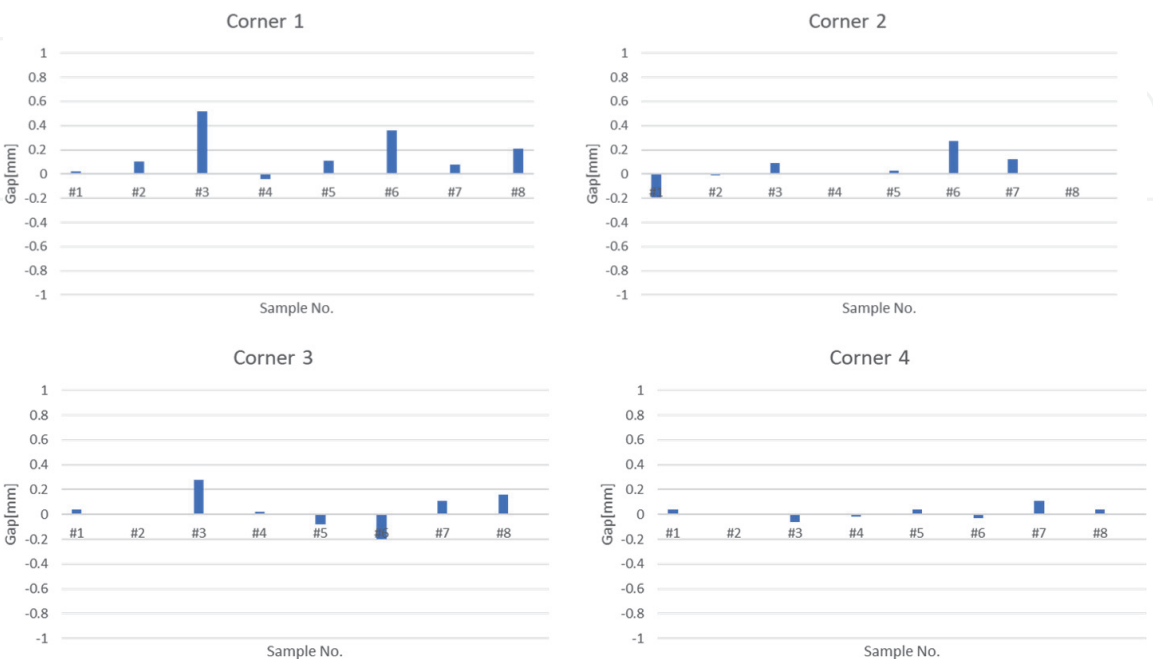


Figure 27.
Gap change at different corners vs. environment conditions.

5.5 Bond line vs. environmental condition 3

Testing has been done to measure the difference of bond line gap change before and after three different environmental conditions. As mentioned in the refrigerator section, polyurethane hot melt adhesive provides an excellent environment resistance. As shown in **Figure 27**, polyurethane hot melt adhesive exhibits a minimal gap change before and after three different environmental conditions. Specimens #1, #2, and #3 are the conditions of thermal cycle 4 h at 70°C/65%RH to 4 h at -30°C (10 cycles); specimens #4, #5, and #6 are on the condition of high temperature 168 h at 70°C; and specimens #7 and #8 are on the condition of high humidity 168 h at 40°C/95%RH. The gap change at 4 corner area of top cover that has a biggest tendency of gap change was measured.

6. Microwave

In this section, we are going to compare 2 component silicone vs. 1 component silicone in terms of process efficiency. Application is for bonding of glass plate to plastic case in the external three front door [3].

6.1 Production efficiency

The 1 component silicone solution is to apply a primer onto plastic case by 0.5 operator (15 s) → place double-sided tape on a few location by 0.5 operator for instant fixing (20 s) → silicone is dispensed by dispenser (15 s) → glass plate is placed on the plastic case and pressed (5 s) → clip and tape are used to fix the bonded assembly by one operator (20 s) → fixed assemblies go through a heating conveyor → after conveyor, tapes and clips are removed by 0.5 operators (15 s) → the assembly stacked onto rack by 0.5 operator (10 s) → rack is placed in the corner of plant for 24 h curing → cured assembly transfer to next process.

The 2 component silicone solution is to apply primer by machine (10 s) → primer drying by fan (10 s) → adhesive dispensing by machine (15 s) → glass plate placed onto plastic case by machine (15 s) → glass plate pressing by machine (45 s) → initial fixture of assembly achieved and transfer to next process.

The 1 component silicone solution takes three operators and many steps, and especially takes minimum 1 day for silicone curing before transferring to next process, while the 2 component silicone solution requires no operator and its processing time from primer application to initial fixture takes only 3 min which is a dramatic improvement of its assembly efficiency, and this solution required a minimal space for the whole process which is another benefit; it requires no heating conveyor, thus eliminates the concern on extra energy consumption and is operator

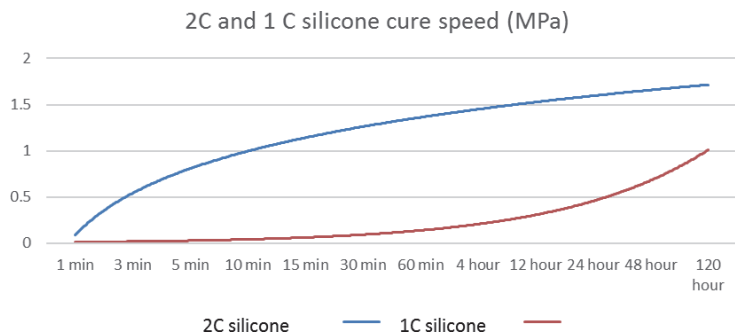


Figure 28.
Fixture time between 2C silicone and 1C silicone.

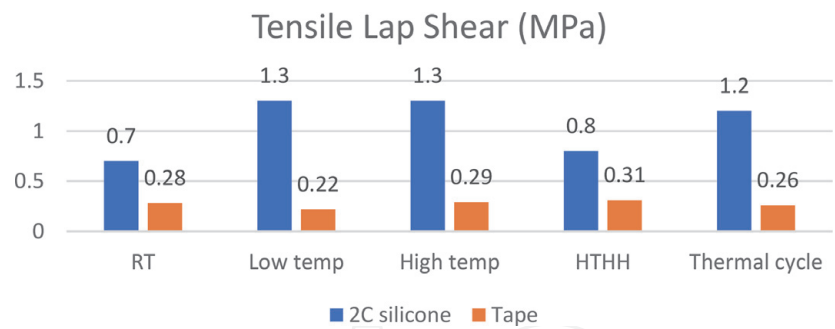


Figure 29.
Tensile shear strength vs. different aging conditions.

safety too; it also increases the quality of the assembly as the time to be exposed to the ambient environment contamination such as dirt sticking to silicone surface is minimal due to its fast cure while the 1 component silicone solution is difficult to avoid such appearance and contamination quality issue. **Figure 28** explains the fast fixture time of 2 component silicone within a short time (3 min) compared to 1 component silicone that takes 24 h to achieve the same initial strength. Using 2 component silicone solution, within a few minutes, the assembly can move to the next process [3].

6.2 Tensile shear strength vs. aging condition

Testing has been carried out to measure a tensile shear strength to compare the bonding reliability before and after aging condition between 2 component silicone solution and tape solution as some manufacturers use tape only without 1 component silicone. Substrate was a ink printed glass and ABS or polycarbonate. Testing conditions were at room temperature (23°C), low temperature (−40°C for 2 h), high temperature (80°C for 2 h), high temperature and high humidity (80°C for 8 h, −40°C for 8 h as 1 cycle for 27 days) and thermal cycle tests (60°C for 4 h to −30°C for 4 h as 1 cycle for 27 days). As shown in **Figures 29**, 2 component silicone solution has at least 3–5 times higher bonding strength for all aging conditions compared to tape solution. Overall, it is very clear that as for environmental durability, 2 component silicone solution provides a far more reliable bonding than tape solution.

7. Conclusions

As reviewed and compared for three appliances on the above such as refrigerator, washing machine, and microwave, those new technologies such as polyurethane hot melt and 2 component silicone solution can help appliance manufacturers open their eyes much wider for new assembly solutions that can provide overall assembly process efficiency such as faster work in process (WIP), automated assembly that can reduce overall man powers and reduce assembly space, increase assembly reliability such as higher bonding strength after severe environment conditions and ultimately the assembly can receive a better reputation and high end image at the market place.

Acknowledgements

This work was supported by various lab engineers who have devoted their time for various and lengthy testing. Great thanks to them for their professional and

technical support as well as administrative aid. Gratitude is also owed to those sales engineers who kindly have contacted manufacturers and received their consent to share with us their actual parts.

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