Study of the correlation between adhesive curing state and handling of digital instrument display for automotive industry

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ABSTRACT

This research was developed within the company Visteon, having as main objectives the study of the curing state and of the mechanical behavior of four structural adhesives and the selection of the best performing adhesive during the assembly process of an automotive display.

The success of joint adhesion depends not only on the adhesives, but also on the substrate used as well as its surface preparation. Consequently, the study was initiated by measuring the surface free energy on three substrates, to assess the substrate wettability when using isopropanol cleaning and plasma pre-treatment. For the adhesive's characterization, Shore A hardness, compression tests and lap shear tests were performed. The shear tests allowed to identify the joints failure mode and to verify the influence of the two surface pre-treatments on the strength of each adhesive.

Forces resulting from pallet movement and from screwing processes were identified as the main forces applied to the display during production. Two tests were developed to reproduce and quantify the two main forces resulting from the assembly process.

Using a real display as an example, it was estimated a curing time before advancing to the next process step. Analyzing all the results obtained throughout the study, it was possible to select the best performing in assembly process.

Keywords: structural adhesive, adhesive joint, surface pre-treatment, automotive display, mechanical properties.

1. Introduction

Adhesive bonding shows some advantages over mechanical joining methods. Adhesive bonded structures are very light and can be relatively cheap to manufacture. Show smooth stress distribution along the bonded length which translates into higher fatigue resistance. The ability to effectively join dissimilar materials is perhaps one of the most important advantages as it allows the use of lightweight materials, such as composites that cannot be joined using other conventional methods. Adhesive joints are used in many industries, as they are more suitable in many aspects such as high strength to weight ratio, design flexibility, damage tolerance and fatigue resistance [1].

This study was proposed by Visteon, an automotive electronics company. Visteon produce, among others, digital instrument clusters and automotive displays. Adhesives, in digital instrument clusters and displays, have become more and more used to obtain lighter and cheaper products. Structural adhesive bonding is one of the most popular methods of joining similar and dissimilar materials, which establishes strong physical bond between the two parts [1].

Structural bonding process can be divided into three stages:

- Surface pre-treatment application (plasma application to both parts, lens and carrier);

- Structural glue dispensing (glue dispensing on one of the parts);

- Bonding (bonding the lens to the carrier).

Adhesives cannot delaminate at any time. They must resist during the manufacturing as well as its products life. There are two main forces applied on the adhesives during the assembly process: shear forces and compression forces. Shear forces occur particularly on moving and stopping of the pallet along the cell, while compressive forces occur mainly when clipping and screwing parts on the final assembly.

The main goal of this research was to find the best mechanically performing adhesive at the assembly process of a digital display. To do so, it was necessary to characterize different adhesive joints (adhesives and substrates) and resultant forces from the assembly process.

2. State of the Art

2.1 Adhesives

Adhesives are the substance that fills the gap between the materials to be bonded. When adhesives solidify, create a bond between the substrates. Adhesives can be divided into five classification methods: molecular structure, chemical composition, physical form, mechanical performance, and curing method [2].

The chemical composition of an adhesive is related to the main polymeric chemical structure in the adhesive formulation. It is the most common way for manufacturers to classify adhesives. In this research 4 adhesives were studied, 3 of them were glues, silane-modified polyurethane (MS1), silane-modified polyether (MS2) and silicone (SIL) and 1 acrylic foam double side tape (DST) were studied.

2.2 Adhesive Bonding

An adhesive bonding process begins with an adhesive application process. When an adhesive cure it creates a bond between the substrates, which after bonding are called adherents. An interface is formed between the adhesive and adherend surfaces. To occur adhesion, it is necessary to make a correct preparation of the substrates, ensuring good molecular contact along the interface, so that a perfect bond occurs, avoiding premature failures [3].

There are several types of adhesive bonded joints, already designed for different types of applications. The single lap-shear joint is the most common due to its simplicity and effectiveness. Adhesive joints can have different types of design, supporting different types of loads. The five main loading modes of an adhesive joint are: tensile, compressive, shear cleavage and peel. In shear load condition, the adhesive layer is relatively well aligned with the load direction. In this load condition, adhesive withstand a greater load and have greater strength [4, 5].

2.3 Wettability

Liquid adhesives, in an ideal scenario would completely wet all surface substrate. But usually, adhesives are repelled by the surface. Adhesive's ability to wet and spread spontaneously on the substrate surface has a real impact on adhesive bonded joints [6].

Wettability degree is determined by a balance of forces between the adhesive and the cohesive forces. In liquid adhesives, the forces of attraction between molecules are in a condition of equilibrium in all directions. But when the liquid adhesive is in contact with the surface, molecules are subjected to forces into the liquid.

When applied to the physical situation of a liquid drop on a solid surface, the surface free energy could be calculated, in terms of dispersive and polar components. Based Young´s equation, and using Fowke's relation, Owrk's model enables to obtain each component of the surface free energy [7].

2.4 Surface Preparation

Surface preparation is a key process to create a strong, long-lasting adhesive joint, as it dramatically affects the level of adhesion between the adhesive and the substrate and consequently to control the strength of the joint. Incorrect surface preparation results in a joint with a low load bearing capacity [8].

There are two major groups in surface treatment: passive treatments and active treatments. In passive treatments, there is no change in the chemical nature of the adherent surface. Active treatments are used for cleaning and removing weak layers, changing the chemical nature of the surface [9].

3. Substrate Characterization

In this section three, three different substrate materials are studied, AZ91D magnesium alloy (MG), painted aluminosilicate glass (PG), and polycarbonate (PC). Magnesium and painted glass are materials used on displays manufacturing process. The glass is painted for aesthetic reasons. It has 3 acrylic-based layers, printed, and cured with UV light. Polycarbonate was chosen because it is not only cheaper and faster to obtain as samples for this thesis, but also for further investigations and feasibility studies.

3.1 Methodology

In this study, Surface free energy (SFE) measurements were tested on three substrates, magnesium (MG), painted glass (PG) and polycarbonate (PC) in three different treatment conditions, non-treated,

cleaned with isopropanol (IPA) and plasma treated.

2µl droplets of both, polar (water) and dispersive (diiodomethane) liquids, were deposited on the substrate and the contact angles were measured by the sessile drop method with a Mobile Surface Analyzer MSA (Krüss) equipment. Measurements were made at 25±1 ◦C and 50±5 % humidity. Plasma treatment was applied manually, through Piezobrush PZ3 (TDK) plasma equipment.

Visteon specifies that 50 mN/m is the minimum SFE in production and for this reason it is also this research SFE benchmark.

3.2 Results and Discussion

After contact angles measurements, the Owrk method was used, and the mean results are presented in Table 1. Both surface pre-treatment mainly increased the polar component of each substrate, especially plasma surface pre-treatment (Figure 1). Plasma pre-treatment increases the polar surface free energy, as the concentration of polar groups increases [10]

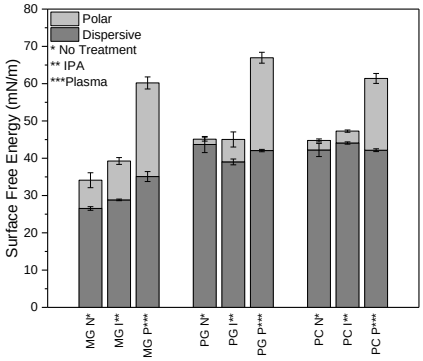

Figure 1 - Polar and dispersive surface energy of MG, PG and PC, with surface pre-treatments

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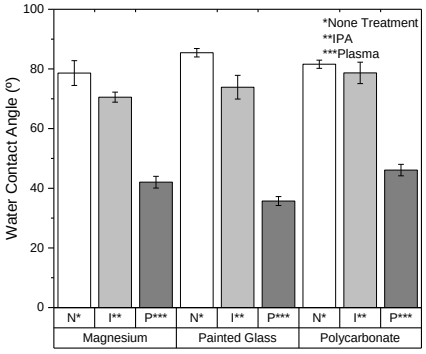

Figure 2 - Water contact angles on MG, PG, PC substrates and IPA and plasma surface treatments

All substrates became more hydrophilic through both surface pre-treatments. However, Visteon SFE benchmark (50 mN/m) was only reached through plasma pre-treatment. Therefore, it is mandatory the use of this surface pre-treatment on all type of adherends.

On the other hand, having the same surface energy does not mean having the same polar effect, for example the virgin and IPA cleaned painted glasses had 85.4º and 73.9º (water contact angle), respectively (Figure 2), even though they have the same surface free energy (45 mN/m).

Moreover, looking at contact angles of the PC sample, the dispersive component barely has any variation, while the polar contact angle is the one that revealed the true effectiveness of the plasma pre-treatment.

These two examples, make it clear that the effectiveness of pre-treatment surface is more simply characterized through only the polar component. Instead of the full characterization with the two liquids. For economic reasons, it is proposed that Visteon can use only the water contact angle as the surface wettability characterization.

Table 1 - Polar energy, dispersive energy and surface free energy calculated through Owrk model

# Test	Substrate	Treatment	γ_S^{pol} (mN/m)	StandDev (mN/m)	γ_S^{disp} (mN/m)	StandDev (mN/m)	γ_S (mN/m)	StandDev (mN/m)	Surface Polarity (%)
#1 - #5	MG	None	7.580	± 1.999	26.532	± 0.491	34.112	± 2.065	22.22
#6 - #10		IPA	10.430	± 0.921	28.834	± 0.222	39.652	± 0.951	26.30
#11 - #15		Plasma	25.108	± 1.614	35.090	± 1.334	60.198	± 1.113	41.71
#16 - #20	PG	None	1.444	± 0.533	43.678	± 2.170	45.122	± 1.670	3.20
#21 - #25		IPA	6.022	± 2.031	39.016	± 0.785	45.038	± 1.355	13.37
#26 - #30		Plasma	24.884	± 1.461	42.064	± 0.314	66.948	± 1.532	37.17
#31 - #35	PC	None	2.558	± 0.399	42.218	± 1.775	44.776	± 1.714	5.71
#36 - #40		IPA	3.184	± 0.309	44.090	± 0.309	47.274	± 1.107	6.74
#41 - #45		Plasma	19.244	± 1.342	42.158	± 0.367	61.402	± 1.073	31.34

4. Adhesive Characterization

In this section, 3 glues, silane-modified polyurethane (MS1), silane-modified polyether (MS2) and silicone (SIL) and 1 acrylic foam double side tape (DST) were studied.

4.1 Hardness Test

Adhesives hardness are typically measured by Shore A Hardness (SAH). In this research hardness was used as an indicator of adhesive's curing.

4.1.1 Methodology

The hardness was measured as a function of curing time. RX-DD-A Digital Durometer (Check-line) measurements were taken at mm away from the edges and least 6 mm distance from the indenter point, according to ISO 868 [11]. The tests were performed under temperature-controlled conditions to the reference temperature of 22 °C. The hardness measurements, for each specimen, resulted from five readings taken at five different positions on the surface.

4.1.2 Results and Discussion

The shore A hardness values obtained were summarized in Figure 3. MS1 and SIL, at 30 minutes after dispensing, were not stiff enough for the hardness measurements. On the other hand, only MS2 hardness was measurable at such short period of time. Curing percentage was presented in Table 2, considering the full cured hardness values from the manufacturer's datasheets. MS2 cures faster than MS1 and SIL adhesives

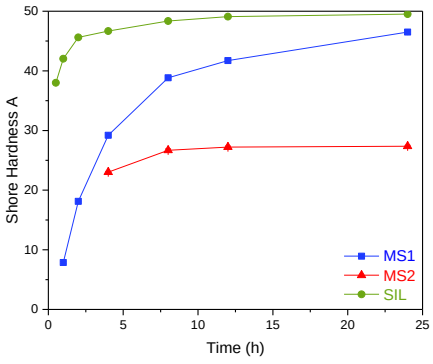

Figure 3 - Shore A hardness vs. time for MS1, MS2 and SIL adhesives

Table 2 - Adhesives curing rate over time (h)

Time (h)	MS1	MS2	SIL
	Cure (%)	Cure (%)	Cure (%)
0,5	-	69.09	-
1	15.41	76.44	-
2	35.53	82.95	-
4	57.25	84.87	76.73
8	76.16	87.93	88.93
12	81.80	89.27	90.73
24	91.18	90.04	91.20

4.2 Compression Test

The main goal of these compression tests was to relate the compressive stresses of the adhesives to the maximum stresses applied when screwing on the final assembly process.

4.2.1 Methodology

All four adhesives, MS1, MS2, SIL and DST, were dispensed along two straight lines, with 1000 mm^2 of adhesive area. After glue dispensing, the pieces were bonded to the glass with a spacing of 2 mm between the mold and the glass. When the adhesives reached the intended curing time for the test: 30, 60, and 90 minutes, the spacers were removed, and the sample was loaded and unloaded.

For each load applied on the sample, the displacement of the adhesive was obtained using ZW-S7040 (Omron) laser sensor equipment. Three samples were tested for each condition

4.2.2 Results and Discussion

Adhesives exhibit both viscous and elastic behaviors as they are viscoelastic materials. Adhesives were more cured, as more time had passed since the dispensing, i.e. the longer the curing time. The higher the slope, the higher the curing rate, the stiffness. The compressive strength (MPa) vs. maximum strain (%) was plotted, for each curing time, for all adhesives.

Table 3 - Minimum curing time for MS1, MS2 and Sil to obtain DST slope benchmark

Adhesive	DST Benchmark	Adhesive Slope	Holding Time (min)
MS1	$y = 7.4x10^{-4}x$	$y=9.8x10^{-4}x$	90
MS2		$y=1.13x10^{-3}x$	30
SIL		$y=8.5x10^{-4}x$	60

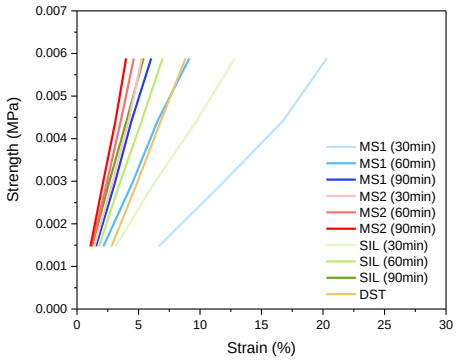

Figure 4 - Linear regression from strength vs. strain plots for all adhesives

The higher the lines clustering, the fastest the curing (Figure 4). There is a big curing rate difference between silane-modified polyurethane (MS2) and silane-modified polyether (MS1). MS2 cures fast than MS1, confirming the hardness curing rate results.

Using DST as a benchmark, the table 4 shows how much time the glue needs to reach the same stiffness. Comparing the linear equations of acrylic foam double side tape and those of the other glues (Table 3), it is concluded that silane-modified 2 requires shorter holding time, before the screwing process, than silicone and silane-modified 1 adhesives.

Table 4 – Linear regression for all adhesives at different curing times (30, 60 and 90 minutes)

Adhesive	Curing Time (min)	Linear Regression
MS1	30	$y = 3.2x10^{-4}x - 0.00074$
	60	$y = 6.4x10^{-4}x + 0.00012$
	90	$y = 9.8x10^{-4} x - 0.00006$
MS2	30	$y = 1.1x10^{-3} x - 0.00022$
	60	$y = 1.3x10^{-3} x - 0.00009$
	90	$y = 1.5x10^{-3} x - 0.00021$
SIL	30	$y = 4.5x10^{-4} x + 0.00007$
	60	$y = 8.5x10^{-4} x - 0.00005$
	90	$y = 1.1x10^{-4} x + 0.00020$
DST	-	$y = 7.4x10^{-4} x - 0.00060$

This approach will be applied in real environment (chapter 5), and the results will be clearer, with a strain estimation for a real display case study, using the linear regression obtained in these compression test.

4.3 Lap Shear Test

The shear stresses for different adhesive joints, varying the adhesive, were calculated by shear lap tests, varying the adhesive, but also the substrate, the curing time, and the surface treatment applied to the substrate. By interest of time, as there was no time to do all combinations, the tests were divided into three methodologies, to characterize all variables. The adhesives and substrates for each methodology were chosen based on the results on the previous one.

4.3.1 Methodology

Lap shear test of the adhesive joints was performed on Instron 5566 [12] universal testing machine, with the load-displacement data being collected using a 10 kN load cell. The tests were displacement controlled with a velocity of 3 mm/min. All experiment were performed at room temperature.

4.3.2 Results and Discussion

1st Methodology

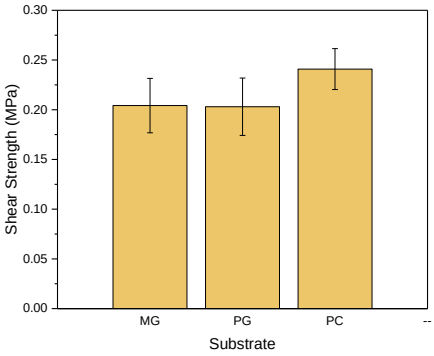

Figure 5 - The substrates were the only variable between the three series.

The substrates were the only variable between the three series. There was no significative shear strength difference between all adhesive joints (Table 5). Polycarbonate was considered the best substrate used because obtained the highest shear strength (Figure 5). A possible reason could be due to the pressure sensitive nature

Table 5 – 1st Methodology, DST shear strength results and failure modes

# Sample	Adhesive	Substrate	Average Maximum Load (N)	Lap Shear Strength (MPa)	Standard Deviation (MPa)	Failure Mode
#1 - #5	DST	Magnesium	63.810	0.204	± 0.032	Adhesive
#6 - #10		Painted Glass	63.448	0.203	± 0.031	Adhesive
#11 - #15		Polycarbonate	75.280	0.241	± 0.022	Adhesive

of the DST adhesive (pressure sensitive adhesive). During DST bonding a set of 500 g weight was used to apply pressure and could be possible that the pressure was not uniformly distributed, meaning the tape could not be fully wetting all surfaces.

Concluding, it is an acceptable choice to use the PC in the next methodology, as was originally intended

2nd Methodology

The second methodology compares the adhesives shear behavior over time (30, 60 and 90 minutes), using isopropanol cleaning as the only surface pre-treatment and polycarbonate as the only substrate, as it was more easily obtained sample.

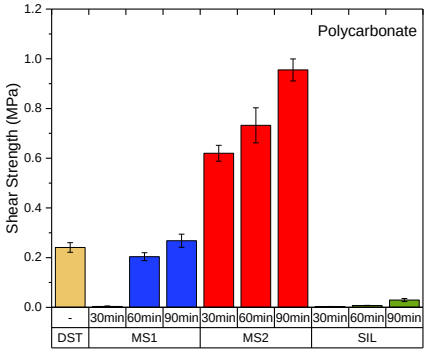

Figure 6 - Shear strength (MPa) for different curing times (DST, MS1, MS2 and SIL)

Table 7 shows the mean values of maximum force and shear strength for each series of specimens and the respective standard deviation for every series.

Silicone had the lowest shear strength among all adhesives, and Silane-modified 2 was the adhesive that showed higher strength in all tests of the second methodology. These results were not expected before lap shear tests, as MS1 full cured shear strength (3 MPa) is higher than MS2 (2 MPa) and SIL (1 MPa).

Table 6 shows an estimation of curing ratio for all glues at different curing times, based on the final curing strength from the manufacturer datasheets (Equation 11). In all 3 curing times silane-modified 2 showed higher full ratio cured strength ratio.

Table 6 - Curing time estimation for three glues (MS1, MS2 and SIL)

Time (min)	MS1	MS2	SIL
	Cure (%)	Cure (%)	Cure (%)
30	0.17	31.00	0.30
60	6.93	36.60	0.80
90	9.23	47.75	2.60

Although less cured compared to the hardness tests, MS2 also cured fastest, followed by MS1 and SIL. MS1 grew slowly but final strength is higher than MS2. Silicone results were not expected. SIL build-up was too low and showed low adhesion.

Table 7 – 2nd Methodology, shear Load (N) and shear strength (MPa) for all 4 adhesives using PC substrate and IPA as surface pre-treatment

# Sample	Adhesive	Substrate	Treatment	Curing Time (min)	Maximum Load (N)	Lap Shear Strength (MPa)	Standard Deviation (MPa)	Failure Mode
#11 - #15	DST	PC	IPA	-	75.280	0.241	± 0.022	Adhesive
#16 - #20	MS1			30	1.519	0.005	± 0.002	Cohesive
#21 - #25				60	65.137	0.208	± 0.018	Cohesive
#26 - #30				90	86.716	0.277	± 0.030	Cohesive
#31 - #35	MS2			30	196.340	0.620	± 0.032	Mixed
#36 - #40				60	228.882	0.732	± 0.079	Mixed
#41 - #45				90	298.501	0.955	± 0.049	Mixed
#46 - #50	SIL			30	0.847	0.003	± 0.001	Adhesive
#51 - #55				60	2.432	0.008	± 0.001	Adhesive
#56 - #60				90	7.983	0.026	± 0.007	Adhesive

Table 8 – 3rd Methodology, shear load (N) and shear strength (MPa) over time for MS2 using MG, PG and PC substrates and IPA and plasma surface pre-treatments

# Test	Adhesive	Substrate	Curing Time (min)	Treatment	Average Maximum Load (N)	Average Shear Strength (MPa)	Standard Deviation (MPa)	Failure Mode
#61 - #65	MS2	Magnesium	10	IPA	88.768	0.284	± 0.046	Coh./Mixed
#66 - #70				Plasma	143.156	0.458	± 0.060	Cohesive
#71 - #75			30	IPA	154.192	0.493	± 0.101	Adhesive
#76 - #80				Plasma	253.784	0.812	± 0.073	Mixed
#81 - #85		Painted Glass	10	IPA	109.164	0.349	± 0.081	Adhesive
#86 - #90				Plasma	154.116	0.493	± 0.051	Cohesive
#91 - #95			30	IPA	202.523	0.648	± 0.072	Adhesive
#96 - #100				Plasma	301.915	0.966	± 0.164	Cohesive
#101 - #105		Polycarbonate	10	IPA	55.389	0.177	± 0.015	Cohesive
#106 - #110				Plasma	90.820	0.291	± 0.044	Cohesive
#31 - #35			30	IPA	196.340	0.620	± 0.032	Mixed
#111 - #115				Plasma	232.937	0.745	± 0.050	Mixed

3rd Methodology

The third methodology goal was to test the surface treatment effect on the shear strength of the adhesive joints. Isopropanol and plasma were the chosen surface pre-treatments in this thesis. In this method, the only constant was adhesive (MS2), because of the better performance shown in the previous methodology. Lap shear samples were done using all three substrates and were tested 10 minutes and 30 minutes after dispensing.

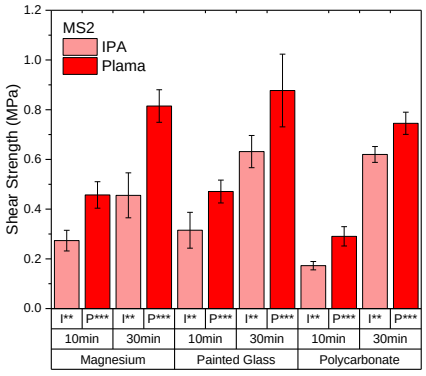

Figure 7 - MS2 shear strength adhesive results over time (10 and 30 minutes) using IPA and plasma pre-treatments on polycarbonate substrate

Figure 7 shows that the adhesive joint strength increased with longer curing times and with plasma surface treatment. Painted glass was the adherent that showed the highest strength in all conditions. These results are according to water contact angle results, using plasma treatment, on Chapter 3: Polycarbonate (46.1º) > Magnesium (42.0º) > Painted Glass (35.7º), lower contact angle, better wettability, higher shear strength. It is also clear, from Figure 7, that plasma pre-treatment increased initial shear strength, which means that it is relevant in initial behavior, as well as in final full cure behavior (Table 8).

The plasma pre-treatment, after 30 minutes was very effective, going from adhesive failure to mixture and to cohesive failure, on magnesium and the glass respectively. In cohesive failures the bonding of the adhesive to the substrate is stronger than the internal strength of the adhesive itself.

Concluding, silane-modified 2 was the adhesive that showed the fastest curing time as well as the highest strength during the first 90 minutes of curing. Plasma pre-treatment significantly improved the adhesion of the joints, which achieved higher strengths whenever plasma was used. The use of plasma pre-treatment in production should be mandatory, as mentioned in chapter 3.

5. Assembly Forces

In chapter 5, the acceleration forces and the forces resulting from the screwing process have been characterized using real assembly processes. This display had 4000 mm^2 adhesive area and weighs 790 g (carrier + lens).

5.1 Screwing Forces

5.1.1 Methodology

For screwing forces tests a five-load cell device was used (Figure 8), developed in Visteon, which could measure vertical forces (perpendicular to the load cells) applied to a product during screwing operations.

Figure 8 - Screwing load cells

5.1.2 Results and Discussion

Screwing forces result in compression forces on the display adhesive joints. The maximum force applied by the screwing process was 38.37 N (Figure 9).

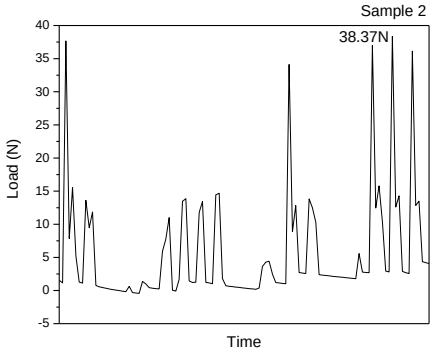

Figure 9 - Sample 2 screwing load (N) over time

Visteon Display

A Visteon display example was used for a better interpretation of the results. The holding times needed before screwing were estimated using previous compression tests results (chapter 4). Dividing the screwing process maximum force, 38.37 N, by the Visteon display adhesive area 4000 mm^2, a compression strength of 0.153 MPa, was obtained resultant of the screwing process.

Visteon defines 15 % as maximum strain specification. Only MS1 and SIL presented more than 15 % strain after 30 minutes of curing for this Visteon display example. But if the adhesive area of MS1 and SIL increases from 4000 mm^2 to 9451 mm^2 and 5626 m^2, respectively, only 30 minutes of holding time are required before the screwing process. These means that product design is also relevant and not only material properties.

5.2 Acceleration Forces

5.2.1 Methodology

Acceleration forces were measured by an accelerometer device Figure 10), a method at Visteon, which was attached to a pallet. The pallet started moving in X direction (Figure 11) after stopper impact, downs, delays a few seconds, then pallet ups and restarts moving forward again.The test was done with 3 different velocities, 120 mm/s, 175 mm/s, and 230 mm/s, each velocity was tested 3 times.

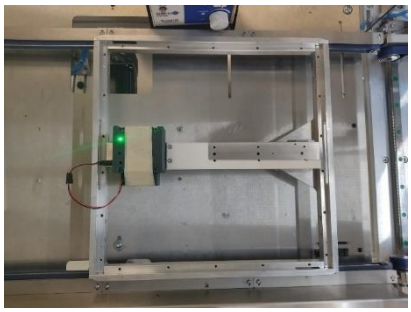

Figure 10 - Accelerometer test

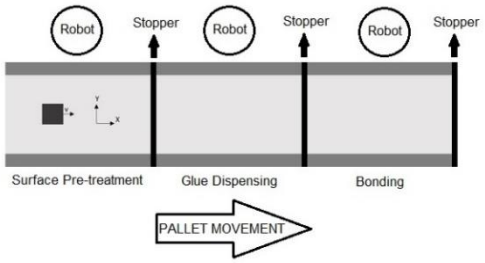

Figure 11 - Pallet movement in structural bonding cell

5.2.2 Results and Discussion

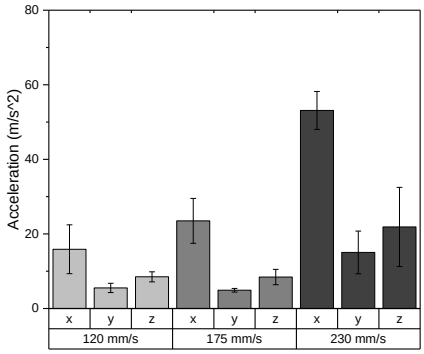

Figure 10 - Acceleration results at different speed (120mm/s, 175mm/s and 230 mm/s)

In all graphs, it was quite clear the pallet impact on the stopper, the descent and ascent movements of the conveyors, and the restart movement of the pallet. The maximum acceleration of 6.01 G was obtained in the direction of pallet motion (x direction), with a pallet velocity of 230 mm/s. The maximum acceleration occurred on the impact of the pallet with the stopper (Figure 21). Converting, 58.94 m/s^2 was the maximum acceleration obtained by the

movement of the pallet along the cell (Figure 12).

Visteon Display

All data obtained from the shear tests were used to estimate the holding time required before pallet movement for all four adhesives. This estimation was made with a real display, produced by Visteon (Figure 87). Visteon display has 790 g and 4000 mm^2 of adhesive area.

Shear strength of the four adhesives were compared with the acceleration strength estimated for the display product. The minimum holding time before Visteon display starts moving after the bonding process, was therefore estimated (Table 9).

Table 9 - Minimum holding time before pallet movement for all adhesives

Adhesive	120 mm/s	175 mm/s	230 mm/s
DST	< 30 min	< 30 min	< 30 min
MS1	30min - 60min	30min - 60min	30min - 60min
MS2	< 10 min	< 10 min	10min - 30 min
SIL	> 90 min	> 90 min	> 90 min

MS1 and SIL needed to hold more than 30 minutes before moving after the bonding process. However, if the pallet movement reduced to 75.4 mm/s and 73.6 mm/s, respectively, the holding time will be reduced to 30 minutes. Pallet's velocity can be reduced just a few instants before stopper impact to avoid a significantly extension of the assembly time.

6. Conclusions

The main purpose of this research was to study the curing state and the mechanical behavior of four adhesives for the selection of the best performing adhesive during the assembly process of an automotive display, short time frame compared with a full cured strength.

Shore A hardness and compression tests showed that silane-modified 2 cured faster than silane-modified 1 and silicone adhesives. This research also analysed the mechanical shear behavior of the 4 adhesives. MS2 showed higher shear strength at different curing times.

Besides wettability improvement, surface pre-treatments had also influence in strength of adhesives and on the failure mode, improving from adhesive failures to mixed and cohesive failures. Plasma is mainly responsible for the increase of the polar component (observed in all substrates), as such it is proposed to simplify surface characterization using only water contact angle.

After a characterization of the substrates and adhesives, this research focused on characterizing 2 assembly forces: screwing forces and acceleration forces. 38.37N was the maximum force applied in the screwing process. From acceleration forces characterization resulted that 58.94 m/s^2 was the maximum acceleration which occurs by moving the pallet along the cell.

All research data was applied on a Visteon display example. It was estimated that after glue application, the silane-modified 2 requires less than 10 minutes of holding time, before being exposed to a pallet movement of 175 mm/s. The screwing process in the final assembly, could be done 30 minutes after dispensing and joining.

MS2 was selected as the best adhesive, due to its faster adhesion build-up compared to MS1 and SIL glues.

Future work

From this research several investigations can be developed: Verification of these research results within Visteon´s production assemblies; FTIR analysis and DMA assays at different curing times, to deepen the knowledge of the curing state of MS2; Study of the ideal heights and speeds for plasma pre-treatment application; Study the mechanical behavior of adhesive joints through peel testing; Development of a method to characterize other forces applied on final assembly process e.g. clipping; Study the topography and roughness of the substrates after plasma pre-treatment.

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