BONDING OF PLASTIC PARTS OPPORTUNITIES FOR FUTURE AUTOMOTIVE CONTUCTION

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INTRODUCTION

Over the last few years bonding has become an established method in the traditional steel-based vehicle construction. Over the years a lot of papers have been presented outlining the advantages which are related to the use of adhesive for structural and semi-structural applications in vehicle body constructions [1,2,3]. Mainly single component, thermal crosslinking adhesives based on epoxies, polyurethane and synthetic rubber are in use. The cure takes place together with the cure of the e-coat in existing ovens. Beside hem-flange and anti-flutter applications structural bonding to replace spot welds or in synergy with spot welding have become important. As weight reduction of the vehicle together with improved safety performance and a cost efficient production are nowadays important issues the use of different Materials than steel will increase in the future. It is very likely that the future car will be a hybrid construction of different materials, steel, light weight alloys e.g. aluminum and plastics [4]. A rather good example illustrating the opportunities of new body concepts is the Chrysler Composite Concept Vehicle (CCV). The body consists of only two molded exterior parts bonded together with two interior pieces. The body assembly is joined to a structural steel perimeter frame that supports the power train and suspension while supplying additional torsional bending strength. The resulting weight of 95 kg is significantly lower than the weight of similar steel-based body which is between app. 150 and 200 kg. [5].

In North America plastic body panels have a 30+ year history, mainly fiber reinforced thermoset material e.g. SMC is in use. A really good example is Chevrolet's Corvette. In 1972 a couple of subassemblies were bonded with PLIOGRIP® two part Polyurethane adhesives, now almost the whole car. Other Examples are:

- Chrysler Jeep Cherokee — Liftgate
- Chevrolet Pick Up — Cap-Top
- Ford Windstar — Front Lid
- GMC APV — Doors and Body Panels
- Chrysler Viper — Doors, Decklid, Chassis
- Ford Mustang — Front Lid
- Paccar Kenworth T2000 — Hole Cab
- Ford Traktor — Roof

This list could be continued for a while, especially with examples from the heavy truck industry. In contrast to the US this technology is quite new for Europe, if you do not count some more or less exotic models (Renault Espace, Fiat Tipo Liftgate). Probably as an effect of the need to reduce the weight of the car to achieve a higher mileage, plastic body panels have gained more and more market share during the last few years. With the liftgate of DaimlerChrysler's A-Class the bad low quality image has been overcome. [6] There are a lot of new applications in the loop or already launched (Volvo V 70 liftgate, Audi A2 Spoiler etc.)

The use of plastic panels automatically requires the use of an adhesive as other joining methods are not suitable. The objective of this paper is to prove that bonding, especially with 2-part PU-adhesives is a suitable, reliable and economic joining method for modern car production.

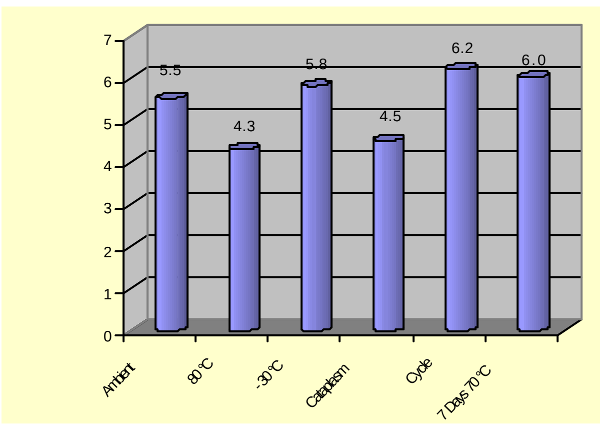
ADHESIVE'S REQUIREMENTS

Plastic body parts in most cases will be manufactured at TIER I/II suppliers and not at the OEM. Therefore the heat of an e-coat oven is not available to cure the adhesive as it is common for the body-in-white adhesives mentioned before. In addition the required cure time of the BIW adhesives are much too long to achieve the required short cycle times nowadays required for a profitable production. It has also be taken into account that novel thermoplastic panels will not withstand the high e-coat temperature of up to 200-210 °C. Again in contrast to the current steel based way of body production other (mechanical) fasteners beside bonding are not allowed and the parts have to stay in a fixture till the adhesive has cured to a certain extend to assure a significant handling strength. A different adhesive system has to be chosen for the manufacturing of plastic parts. Some of the requirements for such an adhesive are listed in fig.1:

- Application by Robot
- Good Sag Resistance, High Body
- Good Adhesion to Different Substrates
- Good Aging Properties, Good Chemical Resistance
- Good Strength Properties, even under Crash Conditions
- …
- Long Open Time
- Fast Cure Response

Fig. 1: Requirements to 2-part Adhesives for High Volume Production

Mainly 2-part PU-adhesives are in use for this kind of application. They offer good mechanical properties, a good combination of strength and elasticity - they are tough (Fig. 2). On the other hand the thermal resistance is limited. Therefore epoxy-based 2-part adhesives are used quite often for parts exposed to higher temperatures e.g. under the hood or close to the exhaust system. The disadvantage of a much less elastic/tough adhesive have to taken into account



Mechanical Properties

Tensile Strength: 25 MPa
Elongation: 70 %
Young's Modulus: 450 MPa

Joint Thickness: 1 mm,
Cure: 3' 110 °C + 24 h RT

Fig. 2: Typical Properties of PLIOGRIP® 2-k-PU Adhesive

One major disadvantage of the use of 2-part adhesive is the strong requirement of an exact metering and thorough mixing of the adhesive to achieve the a.m. good performance. Thanks to the work of the equipment manufacturing industry, supported by the adhesive manufacturers which have developed easy to meter and to mix adhesives this hurdle has been overcome. The viscosity of the two adhesive parts is in the range of 10.000 to 30.000 mPas, and the mixing ratio is close to 1: 1. But there is still the problem of the requirement of a long open time together with a fast cure response. The open time (time window, between dispensing and joining the parts together) should be as long as possible to make the process more robust. In any case the open time has to be longer as the time necessary for dispensing the adhesive and joining the parts together. On the other hand the time to achieve a significant handling strength shall be as short as possible to achieve short cycle times and a good productiveness. Unfortunately both times are contradictory to each other, it is not possible to vary one independently from the other.

Similar to each chemical reaction the formation of a urethane bond by the reaction of an isocyante with and hydroxyl-group can be accelerated in accordance to the Arrhenius-equation by heat. [7]. It is obvious to use this law of nature to achieve both on the same time, a long open time and a short cycle time, just by applying heat to the bond after the parts have been joined. Fig. 3 gives the theoretically calculated conversion rate of a PLIOGRIP® 2-part PU-adhesive at different heat-up rates.

It has to be mentioned that this particular formulation does contain a tailored catalyst mix which becomes most effective at elevated temperature. The catalyst-mix is of significant importance to achieve short cycle times without shortening the open time too much. Traditional 2-part PU-adhesives for sure do not show this fast cure at elevated temperatures or would have a much shorter open time.

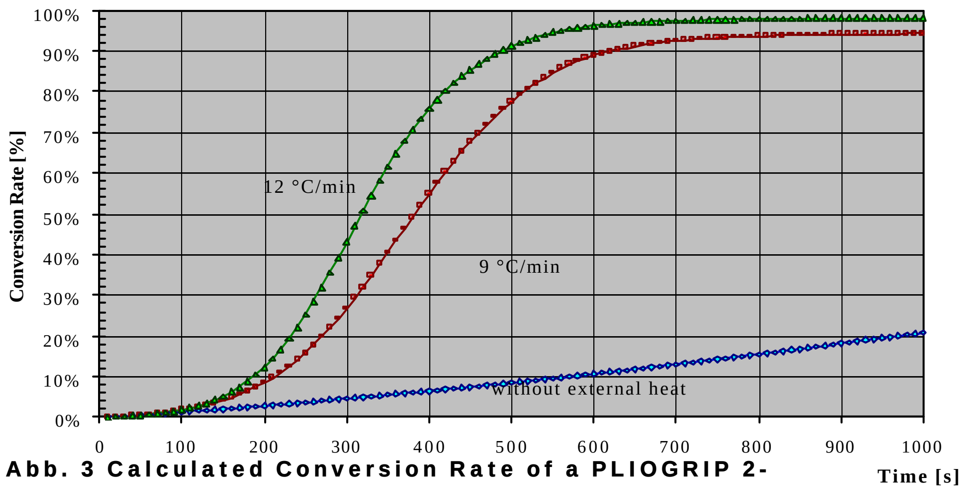


Abb. 3 Calculated Conversion Rate of a PLIOGRIP 2-Part PU Adhesive

TECHNOLOGIES TO APPLY HEAT TO THE BOND

For obvious reasons the adhesive should not be exposed to any additional heat before the parts have been joined together. This would result in an accelerated cure and a shorter open time. There are the following different technologies available to apply heat into the bondline (Fig. 4).

ive Heating	lates Contacting Parts to be bonded
d	by Radiation
requency	es Dipoles in the Adhesive to Create Internal Heat
n Heating	tic Field Causes Metal to Heat
Impingement	Directed at Bond Lines

F*ig. 4: Technologies to Apply Heat*

CONDUCTIVE HEATING

Most of the heated fixtures used so far are based on this technology. The plates are heated either by circulating hot water, steam, hot oil or by electrical resistance rods or coils. The response time to any desired change in temperature of the fixture is quite long. The fixture has to be switched on a certain time before the first part shall be bonded and it takes a few parts to reach a thermal equilibrium.

The adhesive is applied to one of the cold parts, preferably outside the heated fixture, both parts are placed in the fixture and joined by closing the fixture. In most cases the required intimate contact of the part with the heated plate is not achieved and the heat transfer is significantly hindered by any small gab between the fixture plate and the part. This results not only in relatively long fixture times of at least 5-6 minutes but very often also in an uneven temperature distribution along the bond line.

The bonded part has to be removed from the fixture still being hot, to cool down the whole fixture would be much too time consuming. At this stage the adhesive is not fully cured and has not reached its final cohesive strength. If further handling is not carried out carefully the part might be damaged. As the part has to be removed hot, it will cool down in an un-fixtured state. Due to different thickness of the parts or if they are made out of different material stress might be applied due to differences in cooling down. This might result in a damage or distortion of the part.

INFRA RED

In most cases short wave IR-lamps are in use. They offer both a relative fast heat up and a good penetration of the IR-radiation into the substrate. The resulting temperature in the bond line is very much depending on the distance between IR-lamp and the part. This requires an exact adjustment of the lamps along the bond line and regular maintenance. In some cases it is difficult to follow exactly the bondline with a distinct space between part surface and the IR-lamp specially if the bondline is not a straight line. In most cases shadowed areas can not be totally avoided.

Volatiles from the plastic panels as well as dust can reduce the efficiency of the IR lamps, resulting in a slowly decrease of intensity followed by a not sufficient temperature in the bond and a slow down in cure and defective parts.

HOT-AIR-IMPINGEMENT

With the Hot-Air-Impingement bonding process, an infinitely variable, regenerative blower system provides pressurized air to independent low thermal inertia programmable heat sources (Fig. 5). The hot pressurized air is then distributed to the bond flange areas of the parts to be assembled by a system of small-diameter stainless steel tubing which has been precisely installed within a math data cut fixturing.

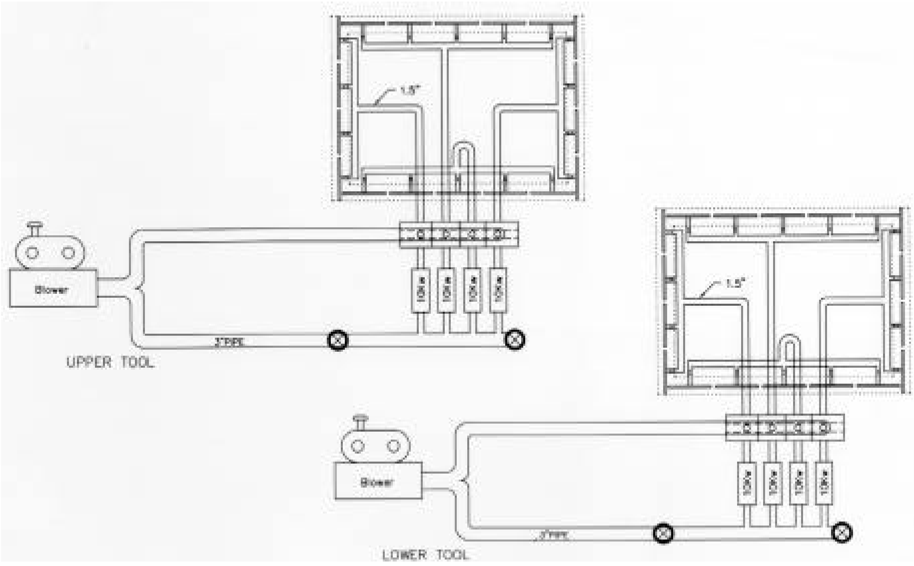


Fig. 5: Schematic Drawing of a Hot-Air-Impingement Fixture (Front Hood) [11]

The tubing is precisely machined relative to orifice diameter, dispersion angle and orifice spacing to produce resonating, high impingement airflow (Fig. 6). Through a typical 2.5 mm wall thickness, adhesives will be activated in most cases within 25 to 35 seconds.

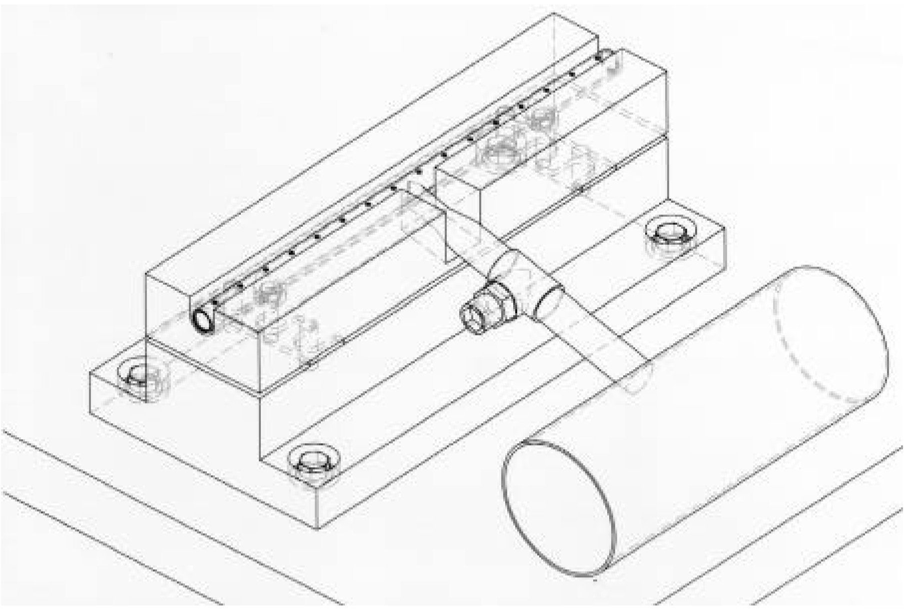


Fig. 6: Hot-Air-Impingement – Tubing [11]

Temperatures in both the top and the bottom tooling components are controlled independently, offering the opportunity to treat already painted surfaces with consideration to avoid any damage or distortion of the surface. At the end of the heating cycle ambient pressurized air is introduced to the distribution system to cool the bond joint area. Allowing the part to cool while fixtured improves adhesive green strength, hence, dimensional stability.

- **Bond Line: 2 x 8 m**
- **Airflow: 2 x 12 m^3/min**
- **Pressure at Orifice: 0,2 - 0,3 bar**
- **Blower System: 2 x 11 kVA**
- **Heating System: 2 x 36 kVA**
- **Air-Temperature: 180 °C**
- **Bond Line Temperature: 110 °C after 70 sec**

Fig. 7: Technical Data for a Typical Hot-Air-Impingement Fixture [11]

The time-temperature-graph typical for a hot-air-impingement fixture and the resulting calculated conversion rate for the already mentioned PLIOGRIP® 2-part-PUadhesive is shown in Fig. 8 and 9. It becomes obvious that the hot-air-impingement technology offers a really fast heat-transfer into the adhesive resulting in short cycle times down to two minutes and less. In the given example after 60 sec as a bond line temperature of 120 °C has been reached ambient air it introduced to the distribution system to cool the bond joint area to improve the green strength of the adhesive and to assure the required handling strength.

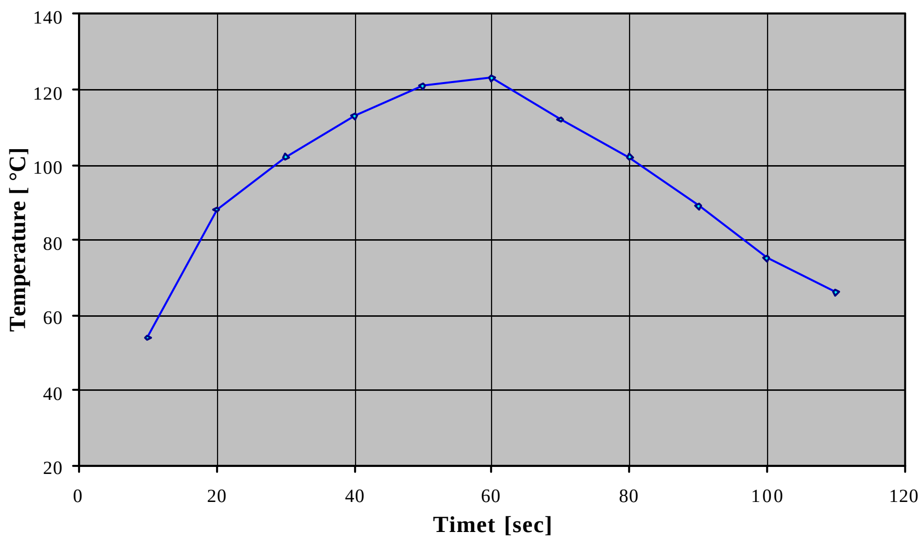


Fig. 8 Time – Temperature - Graph

The first commercial application of the Hot-Air-Impingement technology was in 1995 for Chrysler's LeBaron JX-27 front hood and rear lid. With app. 60.000 units per year it was a typical low volume application. With the start-up of the front hood for the Ford Mustang with 135.000 parts per year in 1996 the threshold to a high volume application have been reached.

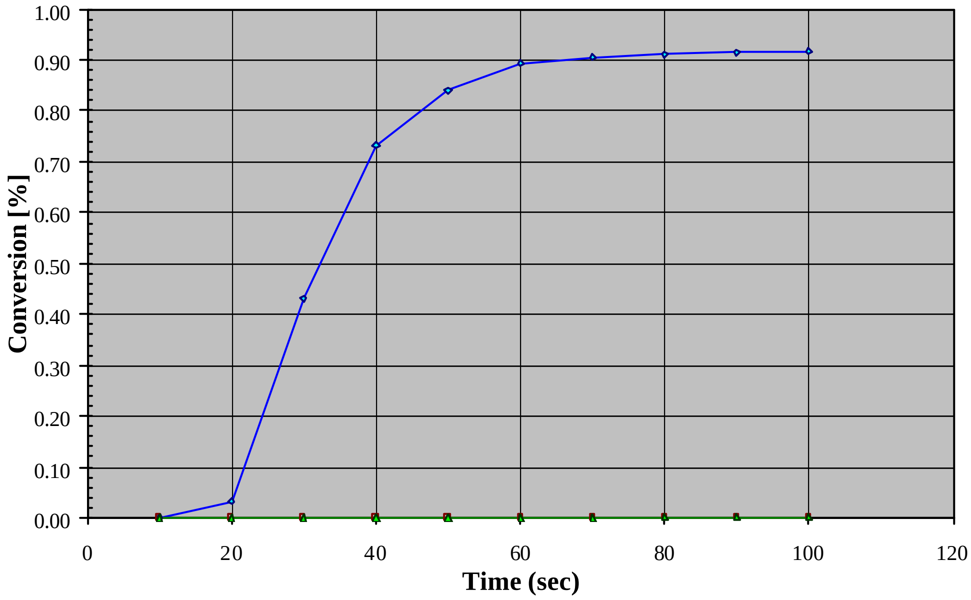


Fig. 8: Calculated Conversion Rate

PACCAR's Kenworth T 2000 was pushing the truck-framing and plastic-skinning technology forward. Many different plastic components and pre-coated metals are structurally joined in fast cycles. Actually the whole cab is bonded together using PLIOGRIP® adhesives and the hot-air-impingement technology. App. 20 kg of adhesive is used for each cab and about 10000 cabs are produced per year. [8]

Ford introduced a new and novel design for interior structural application with the new Ranger and Explorer. The objective was to consolidate parts in the cross-truck beam area using lighter weight, bonded composites and to achieve a less noise vibration harshness performing air-duct instrument panel. In close Cooperation between Ford, the tooling manufacturer and Ashland as both the resin and adhesive supplier the chosen manufacturer Cambridge Industries achieved a part consolidation from 35+ pieces to less than 4 and a 60-second cycle time on two/three hot-air-impingement fixtures. [9]

RADIO FREQUENCY

The radio frequency (27,12 MHz) causes dipoles in the adhesive to create internal heat. Curing with RF energy is very fast and, when used with non-conducting materials like SMC, but it is difficult to use with conductive materials. On the other hand it is very efficient as it heats only the adhesive. A lot of effort has to be taken into the controls as changes in numerous condition decreases its effectiveness. The heat-up behavior depends not only on the radiation power but also on the thickness of the adhesive layer and the amount of adhesive. The thicker the adhesive layer (the more adhesive) the more energy is absorbed and the shorter the heat-up time. [10]

INDUCTION HEATING

This technology takes advantage out of the fact that a magnetic field causes metal to heat up quite rapidly. The technology is therefor limited to metal-containing adhesives or at least one of the parts bonded together has to be metal. Metal as part of the adhesive formulation is problematic in respective of corrosive properties, abrasion, possible influence on the cure mechanism and last but not least involved raw material cost. Induction heating is hard to control e.g. the heat-up rate depends highly on the distance between the coils, inducing the magnetic field and the metal. The is one reason why induction heating is not generally used in composite assembly bonding. It might be a suitable as one of the bonding parts is made out of metal. It. will then offer a quite fast heat up and short cycling time.

COMPARISON OF COST

A cost comparison of the described heating technologies is very difficult as a lot of parameters e.g. number of parts, incorporation into the manufacturing process, available energy sources, energy cost, etc are of significant influence. Looking to the a.m. technical data for a typical hot-air-impingement fixture it becomes obvious that the involved energy-cost is a significant part of the running costs. Being aware of this the manufacturer of hot-air-impingement fixtures are working to reduce the energy consumption significantly.

In regard to the investment cost the following might be taken as a guideline:

lnductive Heating	**Hot-Air-**		**Conductive-**
>	>	and	
RF- Heating	**Impingement**		**lnfra Read Heating**

Although the investment cost of a hot-air-impingement fixture is higher compared to a conventional conductive or IR fixture there are a lot of advantages which make the whole process more profitable and reliable, especially if short cycle times are required.

SUMMARY

The intention of this paper was to show that 2-part adhesives do not only fulfill the OEM's requirements in regard of strength performance and durability. Thanks to novel tooling technologies and adhesive formulations tailored specifically to the requirements of today's automotive mass production, bonding with 2-part adhesives has proven to be a reliable joining technique as plastic materials have to be joined. This can be emphasized by Ashland's 30+ years experience in bonding plastic panels for automotive applications at both low and high volume and will help to achieve the goal to reduce the car's fuel consumption.

ACKNOWLEDGEMENT

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