LATEST ACHIEVEMENTS IN THE FIELD OF ASSEMBLING METALS AND COMPOSITES

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ABSTRACT

Metallic substrates are largely used in aeronautics and space and assembled with several joining techniques including screwing, riveting, welding or bonding. The ever increasing need for lighter materials and assemblies as well as the widespread use of multimaterials assemblies tend to foster the use of bonding, especially multifonctionnal bonds with additional features to mechanical performances, like conductivity, thermal stability or debonding on demand. In order to meet these challenges, RESCOLL has developed, since several years, different adhesives with specific functionalities such as dismantling capability, e&T conductivity or large temperature operation range. These adhesive systems will be presented in the paper.

INTRODUCTION

Multimaterial assembly is identified as one of the key technologies for the development of future programs in the transportation industry. The use of bonding joints and related techniques is in the technological roadmap of major aircraft manufacturers, automakers and manufacturers of space launch vehicles. Today, the cost of assemblies represents between 10 and 30% of the total cost of a system, more specifically assemblies can count for 8% of the manufacturing price of an aircraft and more than 20% of the costs for a rocket section. It has then been clearly highlighted that the use of bonded assemblies within aerospace is generally expensive and time consuming, either in terms of non-recurrent cost during the development phase or in terms of recurrent cost during the production phase. One of the lead that has been identified to minimize such problems is the use of smart or multifunctional adhesives that help to reduce the overall cost of assemblies and also to extend the field of use of such advanced materials.

Since several years, RESCOLL has developed several adhesives considering the different requirement previously enumerated. Such developments have been performed with industrial partners and in the frame of risk sharing, B to B, RAPID, FUI and EU projects.

DEBONDING ON COMMAND

Structural adhesives are nowadays widely used in numerous industries like automotive, aerospace, avionics or microelectronics, etc., for many reasons such as easy processing or weight and cost savings. A strong effort has been achieved so far to enhance the level of adherence in structural assemblies and in this particular case a new challenge appears: the easy dismantling of structural bonded joints. This innovative concept results from industrial constrains like maintenance or recycling needs [1].

We will discuss in this paper the mechanism involved in the process developed and patented by RESCOLL [2] that offers a simple and efficient solution to the disassembling of structural bonds. Based on the use of specific additives activated by heating at a certain temperature, this new technology allows the drastic decrease of the bonding performance and allows the dismantling in a very short time. It fulfills the main characteristics required by this application, like no change in processing (implementation, curing conditions, etc.) and no or slight modification of the mechanical properties. A more detailed description of the technology will be given in the lines below.

This process is based on the incorporation of specific chemicals in the adhesive or primer formulations. These additives are selected according to specific properties like decomposition temperature. An innovative aspect of this technology lies in the localization of the dismantling. The first step of the additive action is migration from the bulk of the adhesive to the interface, as depicted in Figure 1. In a second time, once at the interface, the decomposition gases generated by the additive (mainly steam and nitrogen) induce constrains and stresses. After a certain time, theses stresses are sufficient enough to overcome the adhesion forces and the adhesive debonds from the substrate, adhesive failure occurs. One logical consequence of this interfacial action is the use of a dismantling primer, which enables to improve the efficiency of the technology and allows additive savings.

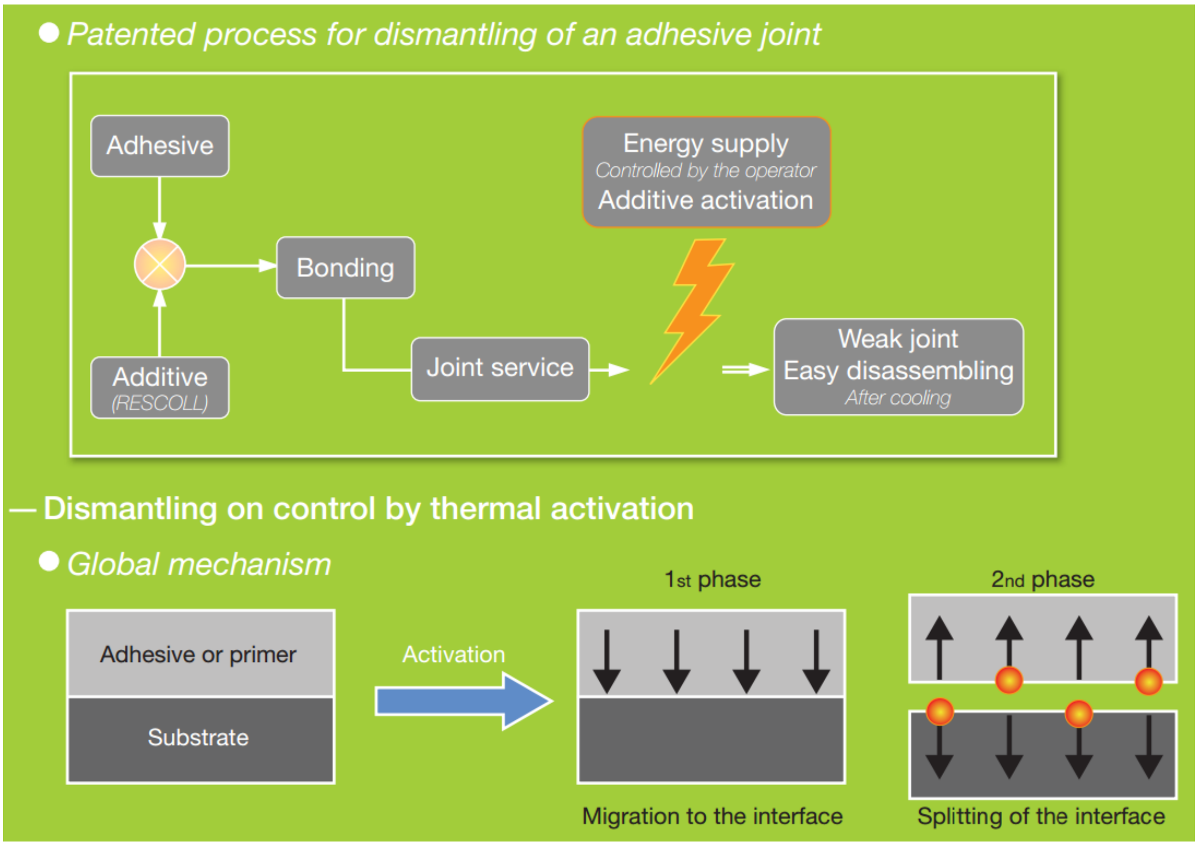

Figure 1: Description of RESCOLL's Debonding on Command Technology (INDAR)

Several industrial partners expressed their interest in the process and studies have been carried out to validate the concept in their applications.

Some examples of collaboration are given below:

- Dismantling of automotive glazing and plastic or composites body parts [3] for recycling or maintenance: reformulation of 1K polyurethane adhesive with specific encapsulated additive. The encapsulation brings chemical stability to the reformulated adhesive. Debonding occurs after an activation of several minutes with an infra-red lamp.

- Debondable adhesive for structural coupling during ground tests in the frame of GAIA telescope. Its main structure is a multi-segments brazed torus in silicon carbide. In order to test each segment, a structural and debondable epoxy adhesive was developed, allowing structural bonding at room temperature and easy dismantling with interfacial failure after thermal activation as shown in Figure 2. After testing and dismantling, segments were reused for final application.

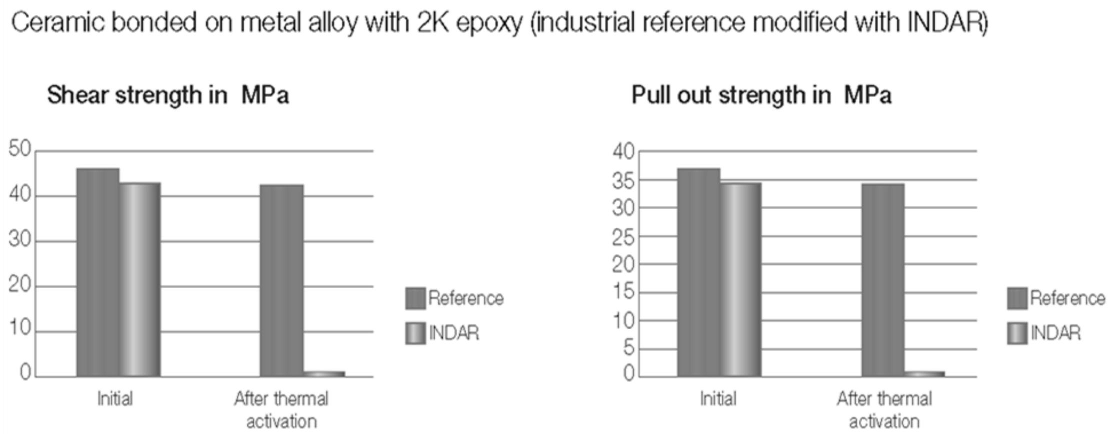

Figure 2: Development of a 2 component debondable epoxy for ground testing of SiC parts

ELECTRICAL AND THERMAL CONDUCTIVITY

The development and use of structural composites and their integration in the design of multimaterial assemblies is an industrial reality that comes along with increased material performances, with an unmatched combination of lightness and strength. However the ever increased use of these assemblies brings new challenges in the field of thermal and electrical conductivity, with an impact on every single component of the assembly is impact, especially the adhesive.

In the frame of the eT-Bond Project (co-financed in the framework of the 11th FUI call), RESCOLL and its partners developed conductive but structural adhesives suitable for use in launchers and satellites applications. One example of application with a need of high thermal conductivity is given below in Figure 3 (Source: MasterBond), however this is only one example in a variety of different uses with dissimilar needs in terms of electrical conductivity, structural performance and thermal conductivity.

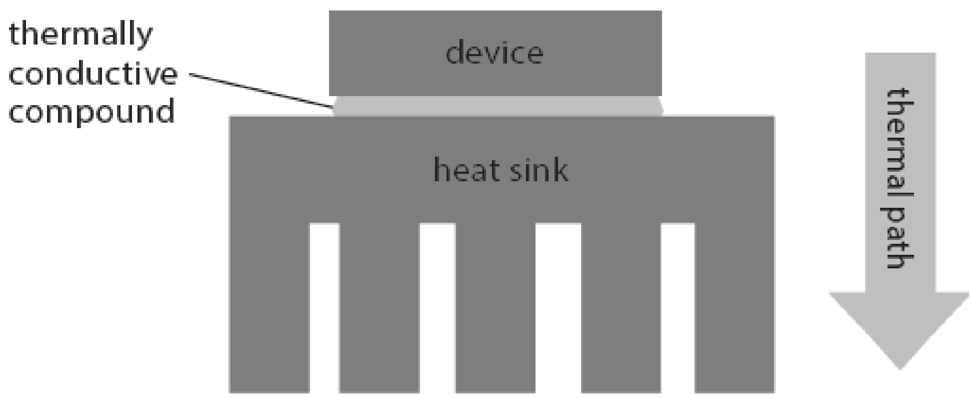

Figure 3: Thermal path in device – heat sink assembly

One interesting part of the project was to collect the different specifications form the Project end users (THALES, AIRBUS DS, AIRBUS GROUP INNOVATION and NEXEYA) and build three different case studies as a basis for the development of the new adhesives. The table presented in Figure 4 is a simplified version of the spec/case studies table coming out of the data collection work. Thermal, electrical and mechanical performances were ranked from 1 to 3 for each application.

Application	Thermal performance	Electrical Performance	Mechanical Performance
Substitution of screws and rivets by adhesive	1	2	3
Bonding of metallic sliders	2	2	2
Structural bonding of hybrid parts	2	2	3
Bonding of heat sink under power supply	3	3	2
Bonding of insert on heat sink	3	1	1
Bonding of radiator on top component	3	0	1
Bonding of component box cover	1	1	3

Structural Adhesive
Thermal Adhesive
Component Adhesive

Figure 4: Summary of the different case studies evaluated in the eT-Bond Project

The eT-Bond Project focused on the synergies between the different functionalizing agents in order to:

- tune thermal and electrical conductivity
- strengthen the matrix to enhance the structural behaviour of the adhesive

In the end, the objective was to propose a range of adhesives exhibiting the performances below:

- high mechanical strength
- electrical conductivity higher than 10^{-2} S.cm-1,
- thermal conductivity in the range of 4 W/(m.K).

Based on this specification work, prototypes formulations were developed by RESCOLL and 2 references scale-up afterwards by STRUCTIL (SAFRAN GROUP) with standard manufacturing equipment and processes.

These 2 adhesives were then fully characterized and successfully integrated in demonstrators built by the end-users.

The tables in Figures 5 and 6 give an overview of the levels of performance reached with these formulations.

	Electrical Conductivity S/cm	Thermal Conductivity W/mK	Lap Shear Strength MPa
Specs for Thermal Adhesive	**$1.10E^{-5}$ to $1.10E^{-3}$**	**>4**	**>9**
Base Material (unmodified adhesive)	**$1^{E}{}_{-15}$**	**0.2**	**24**
Thermal Adhesive	**6**	**4.4**	**10**

Figure 5: Performance of the Thermal Adhesive

	Electrical Conductivity S/cm	Thermal Conductivity W/mK	Lap Shear Strength MPa
Specs for Structural Adhesive	**>100**	**>0.8**	**> 15**
Base Material (unmodified adhesive)	**1^{E}-15**	**0.2**	**24**
Structural Adhesive	**300**	**1**	**19**

Figure 6: Performance of the Structural Adhesive

These 2 adhesives offer possibilities for designers in cases where bonding can be used as replacement of traditional assembly techniques but was up to now not considered because of cost considerations, eT-Bond adhesives are based on cheaper functionnalizing agents compared to competitive products on the market, weight or mechanical performance since eT-Bond adhesives offer higher levels of performances in comparison with benchmark products.

These 2 adhesives are now part of STRUCTIL's portfolio, under references ST 1008C and ST1009C, respectively for the thermal and structural adhesive.

BROAD SERVICE TEMPERATURE RANGE

Epoxy polymers are widely used as structural adhesives in transport industries for their high mechanical resistance, outstanding chemical and weathering resistance but, like any other polymeric material, they cannot withstand use in high temperature environment and other assembly techniques may be preferred if mechanical loads are applied during operation in hot environment. This is especially true in the case of systems for which no or limited temperature curing of the glue is allowed during manufacturing of the assembly, typically the case of room temperature cure 2 component epoxies used in the manufacturing of space systems like satellites or optical components. In addition, chemical regulations threat several components that help to optimize service temperature range of epoxy adhesives. In the end there is a real need for the development of new 2 component room temperature cure epoxy adhesives with extended service temperature range, i.e. products that offer suitable thermomechanical properties on a temperature range from cryogenic conditions up to +150°C. Optimisation of these properties is a major issue in order to ensure required performances and durability of bonded joint. Thermomechanical properties can be influenced by both chemical structure of reactive monomers or pre-polymers (resin and curing agent) and degree of cure of the polymerized adhesive [4].

The work carried out by RESCOLL mainly focused on the influence of curing agents on thermomechanical properties of cured epoxy adhesives. Two epoxy model formulations were studied using a DGEBA epoxy resin cured with two curing agents having different chemical structures: a polyethylene amine and a polyether amine. These model epoxy adhesives were polymerized with different curing processes. The influence of the degree of cure on thermomechanical properties and on bonded assemblies characterised with lap shear tests at 23°C was studied. A mid-time moderated-temperature post-polymerization compatible with industrial requirements such as 1h at 80°C allows to reach optimal thermomechanical properties at 23°C. Bonded joints realized with cured epoxy adhesives were also tested in single lap shear at different temperatures (between -90°C and 150°C). A comparative study between DMA and mechanical testing leads to a better understanding of the relation between chemical structure of model epoxy adhesives (α-relaxation, β-relaxation, crosslink density) and their thermomechanical properties [5] and allowed to develop some interesting formulations, with interesting mechanical resistance (>10MPa) on a wide temperature range as shown in Figure 7.

Testing temperature (°C)	Stress at break (in MPa) *(std deviation)*
-70	23.7 *(1.8)*
-40	26.4 *(0.9)*
23	27.7 *(1.6)*
90	18.8 *(0.1)*
120	14.7 *(0.1)*
150	9.7 (0.8)

Figure 7: Lap Shear Strength (after curing @ 80°C 1h)

CONCLUSION

With the ever increased use of dissimilar joining and the search for lighter assemblies, bonding is a key technology with several advantages compared to traditional joining techniques. However some challenges still need to be addressed, like lack of reversibility, limited service temperature range and intrinsic insulative behaviour. Due to their strong knowledge in the field of material science and especially in adhesives formulation, Rescoll, recognised and certified as Technology Resource Centre (CRT) and Contractual Research Company (SRC) in the field of materials, has carried out several development work in order to tackle these issues and offer new products where smart adhesives are required.

REFERENCES

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