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Polypropylen Carbonate Based Temporary Bonding/ Debonding Triggered by Microwave

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Abstract: This paper addresses the issues that are prone to occur in the process of thinning and polishing ultra-thin wafers, such as deformation, fragmentation, damage, etc. A study was conducted on a photoacid generator (PAG) and graphite powder (C) as a load for polypropylene carbonate (PPC), utilizing microwave heating for bonding layers to achieve a rapid, efficient, and convenient temporary bonding solution. For the (PPC+PAG+C) bonding structure, the highest average shear strength reached 5.1 MPa. During the debonding process, microwave heating of the graphite powder transfers heat to the bonding layer, causing the acid generator within the bonding layer to decompose, facilitating rapid and convenient debonding.

Keywords: temporary bonding; debonding; wafers; Polypropylene carbonate (PPC); microwave

Mikrovalovno prožena začasna vez / ločevanje na osnovi polipropilen karbonata

Izvleček: Članek obravnava težave, ki se lahko pojavijo v procesu tanjšanja in poliranja ultra tankih rezin, kot so deformacije, drobljenje, poškodbe itd. Izvedena je bila študija fotokislinskega generatorja (PAG) in grafitnega prahu (C) kot obremenitvi za polipropilen karbonat (PPC) z uporabo mikrovalovnega segrevanja veznih plasti, da bi dosegli hitro, učinkovito in priročno rešitev za začasno spajanje. Pri strukturi spajanja (PPC+PAG+C) je najvišja povprečna strižna trdnost dosegla 5,1 MPa. Med postopkom ločevanja se z mikrovalovnim segrevanjem grafitnega prahu prenaša toplota na vezni sloj, zaradi česar generator kisline v vezivnem sloju razpade, kar omogoča hitro in priročno ločevanje.

Ključne besede: začasno spajanje; ločevanje; Rezine; polipropilen karbonat (PPC); mikrovalovna pečica

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1 Introduction

Technological advancements are approaching the physical limits of chip size, rendering traditional horizontal integration based on Moore's Law inadequate. By 2020, technology nodes had shrunk to a few nanometers [1]. With the development of three-dimensional integration, it is widely believed to supplement the current Moore's Law. Vertical integration technology is currently being actively developed [2]. The main advantages of 3D integration are not only the small size of IC chips, but also the ability to achieve high-density serial interconnects and low power consumption, which is difficult to achieve with traditional 2D-LSI methods [3]. 3D integration can be achieved through chip-to-chip stacking [4], chip-to-wafer stacking [5,6], or wafer-to-wafer stacking [7,8]. Compared to the other two methods, wafer-to-wafer stacking has the main advantages of uniform integration and maximum

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throughput (as long as the device wafer yield is high) [9], thereby reducing costs. However, thicker wafers are difficult to meet the heat dissipation and packaging requirements of high-end chips, and often require the thinning of the wafer to the desired thickness. When the wafer thickness is reduced to below 200μm, ultrathin wafers become brittle and prone to warping [10]. Therefore, the semiconductor industry has proposed various temporary bonding/debonding technologies to temporarily bond the device wafer to a thicker rigid carrier substrate using an appropriate adhesive [11].

The methods of debonding can be divided into thermal slide-off debonding, chemical debonding, mechanical debonding, and laser debonding [12,13,14]. The drawback of thermal slide-off debonding is the requirement of high temperature, which may not be suitable for some ultra-thin wafers that cannot withstand high-temperature treatment. Additionally, the process of an ultra-thin wafer sliding off the carrier wafer may lead to damage. Chemical debonding involves immersing the bonded substrate into a chemical solution to release the bonding adhesive. However, uncontrolled floating of the device substrate in the solvent bath during and after debonding may cause device failure [15]. Mechanical debonding is a relatively aggressive method of separating ultra-thin wafers from carrier wafers at room temperature using special tools, but it may lead to damage due to the thin and brittle nature of ultrathin wafers. Laser ablation of the sacrificial polymer layer is another method for temporary chip handling. However, the moment of laser corrosion can generate localized high temperatures, which may damage the entire bonded wafer. This method has also been used for controlled transfer of molds between two wafers, such as using polyimide or PET as an adhesive for manufacturing low-cost AFM devices [16]. Debonding is expensive, requiring specialized decryption equipment and taking a long time. PPC (polypropylene carbonate) is a polymer of propylene oxide and carbon dioxide. This polymer has biodegradable properties and can be used for disposable applications. In the field of bonding technology, PPC is readily available, and its excellent adhesive strength allows reconfigured wafers to withstand mechanical grinding. Additionally, its thermal decomposition properties enable easy separation of ultra-thin chips from the carrier wafer by heating the bonded pair to a relatively low temperature. The bonding strength of PPC is dependent on the concentration of the bonding solution, and the bonding effect of PPC varies at different bonding temperatures [17].

In order to overcome the above-mentioned shortcomings, extensive research was conducted in this study on a temporary bonding/debonding scheme based on PPC. A controlled experiment was designed, and ultimately a bonding structure utilizing a microwave heating environment, with PPC as the primary adhesive, a moderate amount of PAG, and graphite powder, was developed. The highest average shear strength achieved was 5.1 MPa. During the debonding process, microwave heating of the graphite powder was utilized, which then transferred heat to the bonding layer, causing the acid generator within the bonding layer to decompose at a lower temperature, leading to the decomposition of the entire bonding layer and achieving rapid and convenient debonding. This temporary bonding/debonding scheme is cost-effective and functionally efficient.

2 Design and experiment

2.1 Bonding/debonding principle

The paper proposes a fast, efficient, and convenient temporary bonding solution using microwave heating of the bonding layer. A microwave oven is a common household appliance used for heating food, operating on the principle of generating microwaves inside the cavity to create a uniform microwave electric field. Although microwaves do not produce heat on their own, when concentrated and directed onto an object capable of absorbing microwaves, the polar molecules within the object undergo intense movement, similar to friction, resulting in the heating of the object and the generation of heat. Graphite powder is capable of absorbing microwaves and generating heat; for instance, when applied to paper, it can even burn a hole through it. In terms of thermodynamics, amorphization is an unfavorable process at equilibrium. When certain materials (e.g., silicon wafers) in the exposed area are directly heated by microwaves, crystallization occurs, while the metal-coated area, which shields radiation and undergoes indirect heating, does not experience crystallization. These results indicate that certain areas of the sample can be shielded with a metal coating to prevent crystallization, while exposed areas can undergo microwave-induced crystallization [18]. The glass substrate used in this experiment does not undergo crystallization during the microwave annealing process .

The main concept of this approach involves using PPC as the primary adhesive and adding a controlled amount of PAG and graphite powder to achieve temporary bonding of two glass pieces. When debonding is required, the bonded piece is placed in a microwave oven. The microwave heats the graphite powder, which then transfers the heat to the bonding layer, causing the acid generator within the bonding layer to decompose. This triggers the breakdown of the entire bonding layer, ultimately achieving rapid and convenient debonding, as shown in Fig. 1.

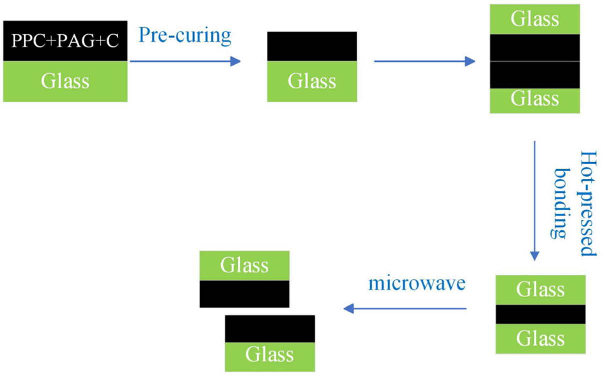

Figure 1: The principle of bonding/ microwave debonding process based on PPC+PAG+C.

2.1 Design of Experiments

Investigation of baking parameters

Procedure: Prepare a 20% mass fraction PPC solution and coat the PPC solution onto a glass wafer. Place glass slides in oven set at different temperatures for solvent evaporation, and then use a hot press to bond the wafers in the air environment. The baking parameters are as follows: temperatures of 70°C, 100°C, and 130°C and baking times of 30 minutes, 30 minutes, and 5 minutes, respectively. Finally, obtain the bonded glass wafer and conduct a residual stress test after it has cooled.

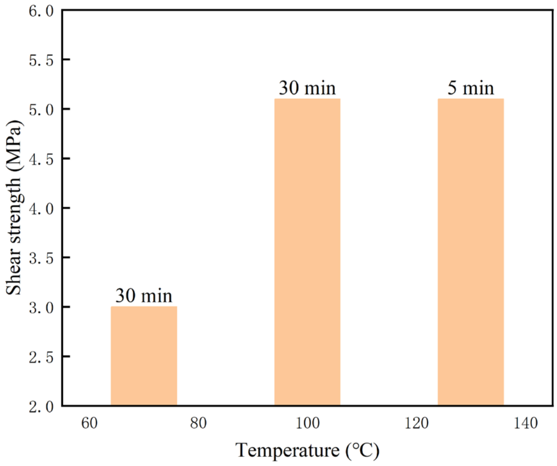

Figure 2: Maximum shear strength of the bonding sheet at different baking temperatures for 20wt%PPC.

Fig. 2 shows that baking at 70°C for 30 minutes resulted in a shear strength of only 3.1 MPa, which falls far short of the desired outcome. This may be due to the temperature being insufficient, leading to slow solvent removal. As a result, after cooling, some solvents may not have been completely removed, causing a loose internal structure in the bonding layer. Increasing the temperature to 100°C resulted in a shear strength of 5.1 MPa, which is more in line with expectations. Further rise of the temperature to 130°C allowed achieving the same effect in just 5 minutes, compared to the 30 minutes required at 100°C what significantly reduced the bonding time and enhance the efficiency of the bonding process.

Investigation of PPC concentration

Bonded glass slides using adhesive with PPC mass fractions of 15%, 20%, and 25% by using baking parameters at 130°C for 5 minutes were prepared. The bonding strength using a shear stress tester (Flat-push tester), for different PPC concentrations, was measured and the result is shown in Fig. 3.

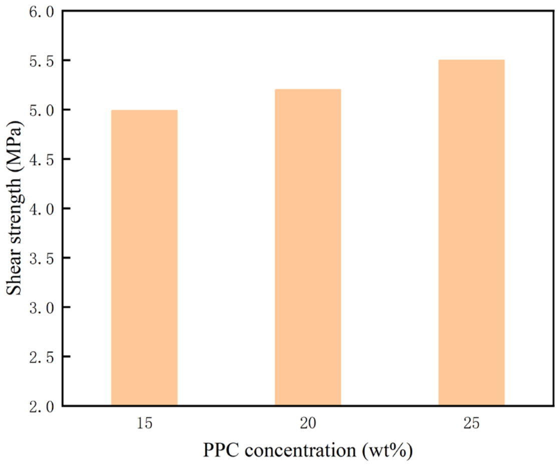

Figure 3: Shear strength of bonding sheets for different PPC concentrations.

The bonding strength is highest for the 20% mass fraction of PPC adhesive, with a shear strength of 5.5 MPa. For the 25% mass fraction, the shear strength is 5.2 MPa and the lowest is for the 15% mass fraction of PPC, at only 4.99 MPa. The photo acid generator (PAG) used in the experiment is 4-isopropyl-4'-methyl-diphenyliodonium tetra(pentafluorophenyl)borate, developed by TCI Corporation. It is capable of generating a large amount of acidic substance starting at 200 °C without UV light exposure. With UV light exposure, it can slowly start acid generation at 100°C. Additionally, the addition of copper powder as a catalyst in the PAG can lower the temperature at which acid generation begins [19,20]. The substrate used is glass and is chosen because, unlike silicon, it does not hinder the absorption of microwaves.

In order to verify if the addition of graphite powder in the (PPC-PAG) adhesive allows debonding with microwaves at lower temperatures and to study the phenomena during debonding the following preliminary experiment was conducted, as shown schematically in Fig. 4.

Experimental Scheme

The pre-mixed PPC-PAG solution was applied to two glass pieces for pre-curing. Pre-curing refers to the curing of the bonding agent before baking. The purpose of this step is to allow the bonding agent to lose some of its solvents, forming a shape with a raised edge and a concave center. Dry graphite powder(15 mg) was then added to a 100mm^2 glass piece and flattened to ensure good contact with the bonding layer while maintaining good compaction. The bonding was then carried out using a hot press according to the parameters shown in Table 1. During this period, the bonded piece with added graphite was tested while still in the bonded state. After cooling down from bonding, the glass pieces were placed in a Panasonic DS2000 microwave oven with 1000 W of power at a frequency of 2.45 GHz along with a cup of water to prevent accidents. The pieces were exposed to microwaves for a certain period of time to achieve debonding The experimental results will be discussed in Section 3.

Table 1: Adhesives and bonding parameters

Parameter	Value	
Bond serial number	1	2
PPC quantity vol. (%)	20	20
PAG quantity vol. (%)	5	5
Graphite amount (mg)	15	0
Pre-curing temperature (°C)	25	25
Pre-curing time (min)	1	1
Curing temperature (°C)	130	130
Curing time (min)	5	5
Pressure (MPa)	0.2	0.2

In comparison to the preliminary experiment, three temporary bonding options were prepared to test the effectiveness of microwaves in heating the bonding layer for debonding.

The determination of graphite parameters for the three options is shown in Table 2, while the bonding agent uses 20wt% PPC and 5wt% PAG. The three bonding options, depicted as Options A, B, and C are shown in Fig. 4. Option A involves directly mixing graphite into the adhesive, thoroughly stirring it, applying it to the glass slide, and then bonding it using microwave heating. Option B utilizes water-soluble graphite with better microwave absorption properties in the pencil tip, allowing it to achieve higher temperatures when subjected to the same microwave exposure, furthermore, in B paper is coated with graphite on both sides and placed between the bonding layers to ensure evenly distribution of graphite powder on the white paper. In Option C, after pre-curing the glass slide, graphite powder is added and compacted in the central part of the glass slide, followed by solidification bonding.

Table 2: Selection of graphite parameters

Option	Graphite quantity	Graphite composition	Paper area
A	15 mg	Graphite powder	\
B	Covering a piece of paper	Water-soluble pencil	1cm^2
C	15 mg	Graphite powder	\

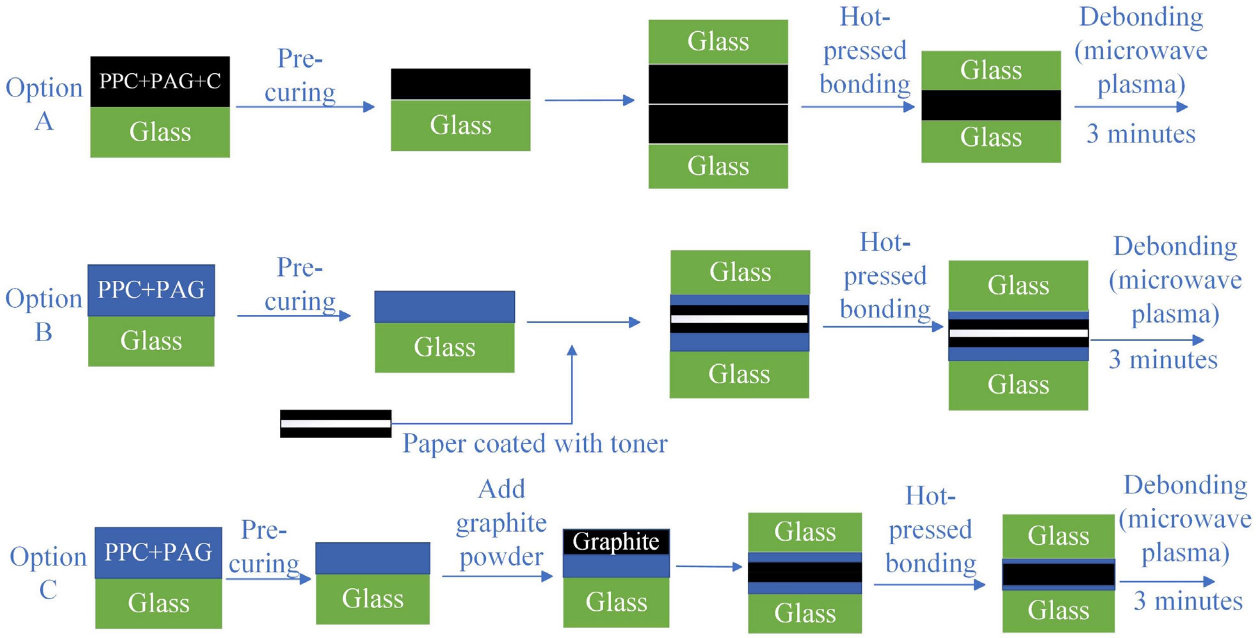

Figure 4: Three temporary bonding options marked as Option A, B, C. Debonding is the same for all bonded options, i.e. microwave treatment took 3 minutes.

3 Results and discussion

Our experimental results show that after adding graphite to the original bonding option (PPC+PGA) the shear strength of the bond can still be maintained at the same level. Fig. 5 shows the appearance of the two glass sheets with and without the addition of graphite powder in the bonding layer after heating at 180°C for 5 minutes. The bonding layer produced a reddish-brown substance due to acid decomposition and reaction with the PPC adhesive, forming a liquid with flow-like properties and emitting a certain amount of irritating gas. Because the graphite powder has a certain particle size, some cavities are formed in the middle, containing a mixture of gases produced by the decomposition of the adhesive and air. The presence of air inside the cavities leaked in during the decomposition process when the gas slightly lifted the glass sheet. After cooling, the remaining material was measured for bonding strength as shown in Fig. 6. It can be observed that the bonding strength of the remaining material bonding layers has significantly decreased. The maximum shear strength of PPC+PAG is 2.98 MPa, while PPC+PAG+C is 3.99 Mpa. The bonding strength of the adhesive with added graphite is stronger than that without graphite, possibly because the addition of graphite increases friction, resulting in a greater force required to push open when measuring the shear stress. Fig. 7 shows the separated glass sheets.

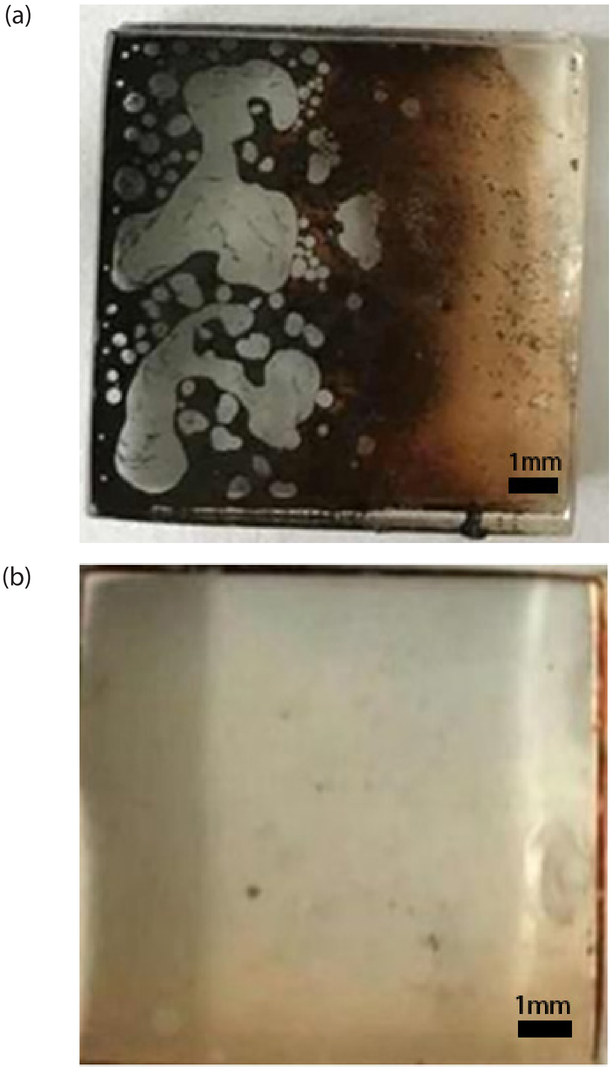

Figure 5: Heating the bonding samples at 180°C for 5 min: (a) with and (b) without added powder graphite.

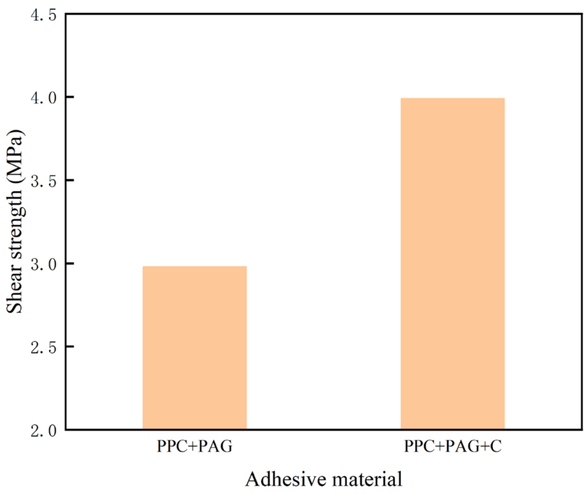

Figure 6: Shear strength of bonded samples for process without and with added powder graphite.

In Option A, the bonded sheets showed no significant temperature change after microwave treatment because the heat generated during the graphite bonding was diluted by the adhesive, preventing it from concentrating. In Option B, the bonded sheets also showed no significant temperature change after microwave treatment because when the graphite was applied to the paper, most of the contact area was with the paper rather than the adhesive, so any heat generated was unlikely to propagate to the adhesive or the glass surface. In Option C, the bonded sheets showed a significant overall temperature increase for at least 100°C after microwave treatment, along with a noticeable pungent odor from the decomposition of the acid and its reaction with the PPC. Some of the adhesive on the glass has disappeared, and the remaining adhesive is mixed with graphite powder. Through comparison with the control group, the bonded sheets just removed from the microwave could be pushed open manually with a tool, and the surface of the adhesive exhibited a filamentous appearance, indicating that the required temperature for bonding had been achieved. In summary, options A and B were unable to generate sufficient heat for debonding with microwave plasma treatment, while the process C successfully demonstrate use of microwaves for rapid and convenient debonding.

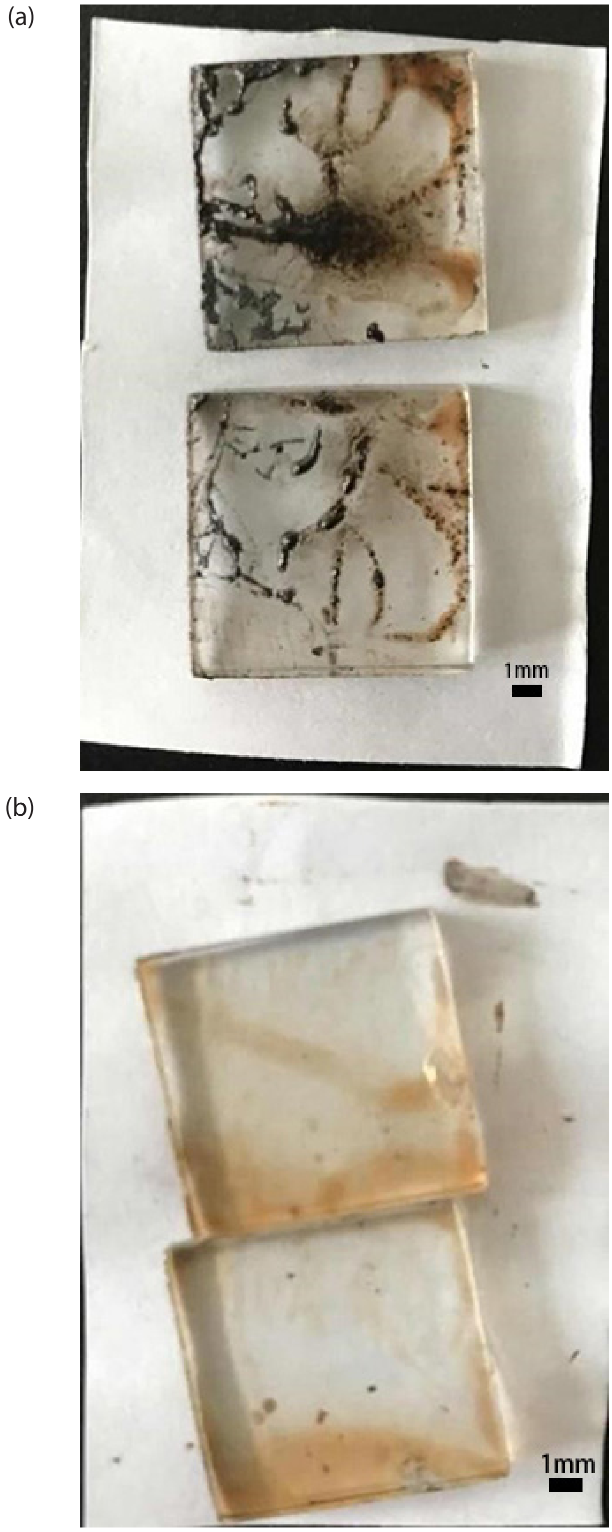

Figure 7: Stripped bonding piece after debonding (a) with and (b) without added powder graphite.

After comparing the three experimental bonding/debonding option, it can be concluded that process option C is the most effective. In this process, the bonded sheets showed the formation of a yellow-brown substance on the surface after microwave treatment what require less force to debond. The adhesive appeared in a liquid state and the glass sheet remains undamaged. This process scheme of temporary bonding/debonding it met all the expectations of the experiment such as low cost and high efficiency.

4 Conclusions

In this work the temporary bonding solutions using a photogenerated acid generator (PAG) and graphite powder © as a load for polypropylene carbonate (PPC), with the bonding layer heated by microwaves to achieve a fast, efficient, and convenient bonding/debonding process were investigated. For the (PPC+PAG+C) bonding structure, the highest average shear strength reached 5.1 Mpa. For the debonding process, microwaves were used to heat the graphite powder, which then transferred heat to the bonding layer, causing the acid generator inside the bonding layer to decompose at room temperature, leading to the collapse of the entire bonding layer and thus it is achieved rapid and convenient debonding.

Among the three different process options introduction of powder graphene in the bonding/debonding scheme, only the process option C resulted in efficient debonding with microwaves at room temperature.

5 Acknowledgments

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6 Conflict of interest

The authors declare that there are no conflict of interests.

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