Adhesive Bonding of Polymeric Microfluidic Devices

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Abstract

This paper investigates the use of adhesive bonding on polymeric microfluidic devices. Both pressure sensitive and UV curable adhesives have been studied. Characterization tests conducted include flow, pressure and 180° peel tests. All the five adhesives are able to pass the flow and pressure tests. Pressure sensitive adhesives generally perform better than UV curable adhesives in the peel tests due to the different substrates used. With careful application of the adhesives, UV curable adhesives show less sagging into the microfluidic channels as compared to pressure sensitive adhesives.

Introduction

Polymeric microfluidic devices are increasingly used as versatile alternatives to silicon microfluidic devices due to their lower cost and easier fabrication routes. A variety of polymers have been used, and they range from polymethylmethacrylate (PMMA) to polyvinyl chloride (PVC). Several bonding techniques such as thermal [1, 2] and solvent bonding [3] have been reported for the sealing of the polymer microfluidic chips, and due to the simplicity of the method, adhesive bonding is also one of the techniques that is being used. The use of liquid adhesives that set through the evaporation of solvent or curing are some techniques that have been explored [4]. Dry lamination pressure sensitive films have also been used for the bonding of microfluidic devices [5]. The adhesive bonding technique is often met with the challenge of channel clogging due to the flow of the adhesive into the channels. Till now, there is no systematic study on the effect of different adhesives on channel clogging. The influence of the microfluidic channel width is also not considered. Accordingly, this work attempts to explore the use of various types of pressure sensitive films and UV-curable adhesives to bond the polymer microfluidic chips. Characterization tests such as flow, pressure and peel tests are carried out on the bonded microfluidic chips to determine the effectiveness and viability of the bonding technique. The influence of the various adhesives on channel clogging is also examined, together with a study on the influence of channel width on adhesive flow.

Experimental Procedures

The microfluidic chip used for this study is shown in Fig. 1. This capillary electrophoresis (CE) chip is machined using CNC routing and the substrate material used is polymethyl methacrylate (PMMA). For pressure sensitive adhesive (PSA), polycarbonate (PC) cover of 250 µm is used, while polyethylene terephthalate (PET) cover of 50 µm is used for the UV-curable adhesives (UVA). PET cover is used for the UVA because a thinner, and hence more conforming cover is required to prevent voids formation during bonding. There is a limitation to the thickness that can be achieved in a PC cover.

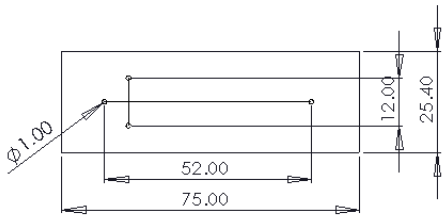

Figure 1. CNC routed CE chip

A total of three different types of optically clear PSA tapes from 3M and Adhesive Research, Inc (AR) were used for the packaging of the CE chip. Two different optically transparent UVA from Dymax and Globalbond were chosen. The adhesives thickness and the temperatures that the adhesives can be subjected to in operation are given in Table 1.

Table 1. Specifications of PSA and UVA.

Adhesive	Type	Thickness (micron)	Temperature (°C)
3M 8212	PSA	50	+177 (short period) Range: -40 to +80
AR 8154	PSA	25	+150 (short period) Range: -29 to +121
AR 8932	PSA	50	+260 (short period) Range: -73 to +200
GB 214	UVA	-	Range: -50 to +150
Dymax 3083	UVA	-	Range: -54 to +150

A simplified procedure to prepare the microfluidic chip for PSA bonding is as follows:

1. Clean the PMMA chip gently using isopropanol solvent and wipes.
2. Peel off one side of the release liner on the adhesive tape.
3. Laminate the tape onto the PC cover using a roller to ensure even pressure distribution and at the same time eliminate voids entrapment.
4. Peel off the 2nd release liner from the adhesive tape.
5. Adhere the PC cover onto the PMMA chip using a roller.
6. Ensure good contact of adhesive to PC cover by moving the roller back and forth repeatedly on the laminated chip.

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For UVA bonding, a simplified procedure is given as follows:

1. Clean the PMMA chip gently using isopropanol solvent and wipes.
2. Apply a uniform layer of UVA on the PMMA substrate using a brush, taking care to avoid the channels.
3. Adhere the PET cover onto the PMMA chip using a roller, removing any air voids during the process.
4. The assembled microchips are then placed in the UV chamber with an intensity of 150mW/cm^2 for 60 seconds for curing.

For flow test, a drop of diluted food dye is put at one end of a channel of the bonded chip, a vacuum suction tube is placed at the other end. The color dye will fill up the whole channel if there is no blockage in the device as shown in Figure 2.

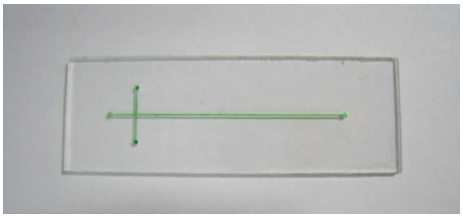


Figure 2. An example of a bonded chip that has passed the flow test.

For pressure test, all the inlet/outlet ports are sealed with epoxy except for one inlet where the pressure is applied. A pressure gauge is used to monitor the static pressure applied to the device. The applied pressure is first set at 1 bar for 2 minutes. A drop in the pressure gauge reading or bubbles formed in the bonded chip indicates failure due to pressure leakage. The chip is thus concluded to have failed at that tested pressure. If no leakage occurs after 2 minutes, the pressure is set to increase in steps of 1 bar and held for 2 minutes at each interval pressure. The maximum applied pressure on the chip is limited to 7 bar. A sample size of three was used for both the flow and pressure tests.

180^o peel tests are carried out on both the PSA and UVA using PMMA-PC and PMMA-PET substrates respectively. The peel tests are conducted using Instron 4505 at a uniform rate of 5.0 ± 0.2 mm/s (ASTM D3330).

In order to determine the degree of adhesive sagging into the micro-channel, the bonded chips were cross sectioned. A black epoxy is used to fill up the micro-channel. This is to minimize the deformation that can occur due to the cutting and lapping processes. The chips were then potted with room temperature curing epoxy and lapped using silicon carbide grinding paper and polished using diamond slurry. The heights of the adhesive outside and within the channel were measured, and were labeled as T_a and T_s respectively as shown in Figure 3. The thickness of the adhesive sagging into the channel can then be calculated by T_s-T_a.

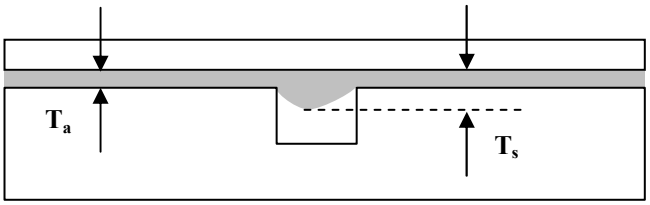


Fig. 3. Schematic diagram showing cross-sectional view of the channel and the method of measuring the amount of adhesive sagging into the channel.

Results and Discussion

The results of the flow and pressure tests are shown in Table 2. It can be seen from the table that both PSA and UVA are able to pass the flow test. The fluid is able to flow freely in the channel with no channel blockage detected. It was anticipated that there could be a certain thickness of the adhesive found in the channel and sagging of the adhesive into the channel is also possible. Cross-sectional test results presented in the later section will confirm this possibility. Pressure test results show that there was no sign of delamination or voids formation in the bonded chip for all the adhesives tested. A test fluid pressure of 7 bar is considered relatively high and gives a good indication of the reliability of the bonded microfluidic chip under pressurized liquid flow. The flow and pressure tests are preliminary characterization tests that determine whether further tests such as cross-sectional analysis and temperature tests should be carried out.

Table 2: Results of flow and pressure tests

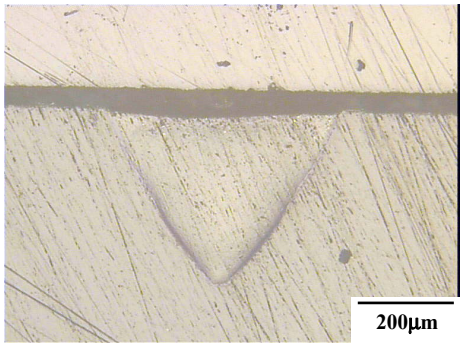
Adhesive	Flow Test	Pressure Test
3M 8212	Passed	Passed
AR 8154	Passed	Passed
AR 8932	Passed	Passed
GB 214	Passed	Passed
Dymax 3083	Passed	Passed

The 180^o peel test results are shown in Table 3. It can be seen from the table that 3M 8212 gives the highest peel strength as compared to the other four adhesives. The PSA generally perform better than the UVA. This is mainly due to the PET substrates that are used for the testing of UVA. PET is considered as a low energy substrate, therefore, bonding is more difficult and the adhesion strength is lower than when PC substrates are used. This peel strength obtained gives an indication of the handling strength of the bonded chips. Table 3 shows that PSA will give a better handling strength than UVA. However, as no delamination of the bonded chips occurs during handling and testing of the chips, the peel strength of all the adhesives are still within the acceptable range. Should harsher handling conditions be required, adhesives that give higher peel adhesion results, such as PSA, would be recommended.

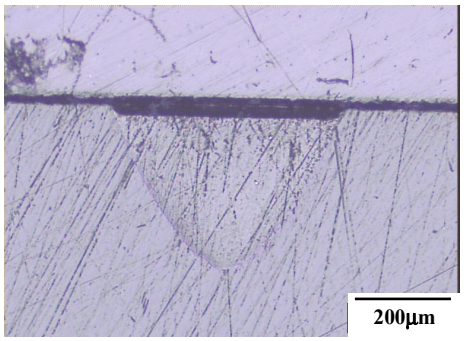
Table 3. 180° peel test results of the five different adhesives

Adhesive	N/mm
3M 8212	2.65
AR 8154	2.25
AR 8932	1.11
GB 214	0.86
Dymax 3083	0.87

The cross-sectional analysis results are shown in Fig. 4.



(a)



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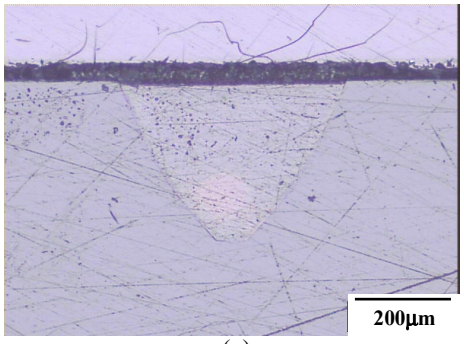

(c)

Fig. 4. Cross sectional analysis of (a) 3M 8212, (b) AR8154 and (c) AR 8932 adhesive tapes on bonded microfluidic chips.

It can be seen from Fig. 4 that all three types of PSA show signs of sagging into the microchannels. The sagging is more prominent when the AR8154 adhesive is used (Fig. 4b). AR 8154 is the only 25 µm PSA that is used. The thinner adhesive is more conformable and is found to deform more when pressure is applied during bonding. The thicker adhesives (3M 8212 and AR 8932) are found to be able to retain their shapes better during the bonding process.

The width of the microchannels is one important factor which should be taken into account when the sagging of the adhesive is considered. Due to the CNC routing process, the width of the channels is usually inconsistent and dimensions can vary up to 10-20% for a 500 µm channel. To determine the effect of channel width on the amount of adhesive sagging (T_s-T_a), channels of different widths were cut using the CNC machine. 3M 8212 was selected to study the effect of the change in channel width. Fig. 5 shows the result of the study.

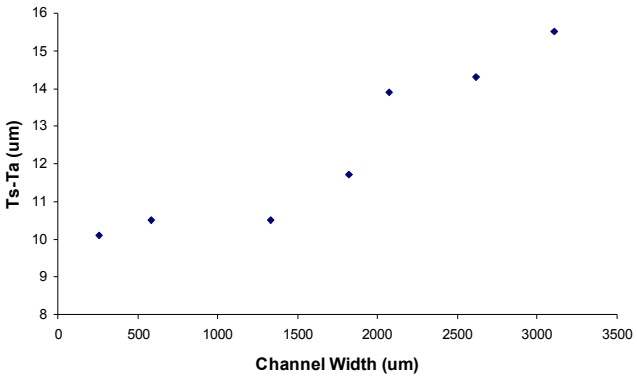

Fig. 5. Effect of channel width on adhesive sagging

It can be seen from Fig. 5 that when the channel width is below approximately 1300 µm, any change in the channel width will not have a substantial effect on the amount of adhesive sagging into the channel. The amount of adhesive deforming into the channel is found to be kept within 10-11 µm, which is a very minimal variation. When the channel width exceeds 1300 µm, a change in the channel width of even 10% will have a more prominent effect on the sagging of the adhesive. As the channel width increases, the tendency for the adhesive to sag due to gravity becomes higher as the support from the side wall of the channel diminishes. In this study, the microfluidics channel is kept to about 500 µm ± 20%, therefore, the variation in the channel width will have insignificant effect on the sagging of the adhesive.

Fig. 6 shows the cross-sectional analysis of UVA GB 214. The adhesive layer is not readily visible from the micrograph as the thickness of the adhesive is estimated to be about 10 µm or less. As can be observed from Fig. 6, the amount of adhesive in the channel is insignificant and does not pose a problem of channel blockage. However, extra care must be taken during the application of the adhesives to ensure that the latter do not flow into the channels. The same is observed for Dymax 3083.

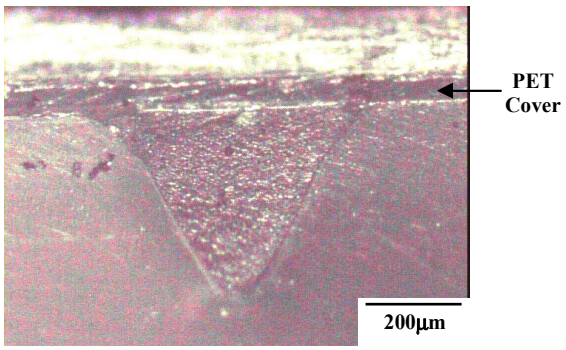

Fig. 6. Cross-sectional analysis of UVA GB 214

Although both UVA GB 214 and Dymax 3083 do not pose a problem of channel blockage, Dymax 3083 tends to lead to a higher entrapment of voids in the bonded chip. As the viscosities of both types of adhesives are similar, the wettability of the two different types of UVA to the PET substrate was investigated. From contact angle measurement, it was observed that GB 214 has a slightly lower contact angle, θ (angle measured shown in inset in Fig. 7) as compared to Dymax 3083. This means that GB 214 can wet the PET surface better than Dymax 3083, and this could account for the lower void content in microfluidic chips bonded using GB 214.

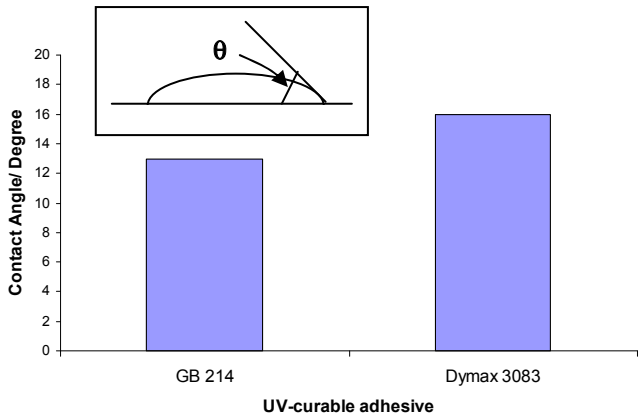

Fig. 7. Contact angle measurement results of UV-curable adhesives (GB 214 and Dymax 3083)

Based on the few characterization tests conducted, it was found that PSA 3M 8212 is able to pass the flow and pressure tests, has the highest peel strength and shows minimal sagging of adhesive into the channels. This adhesive would be recommended for use in the bonding of PMMA microfluidic chips. For UVA, extra care must be taken during adhesive application to ensure that the adhesives do not flow into the channels and to avoid air bubbles trapped. The types of cover materials that can be used to bond the chip are also limited by the thickness of the covers.

Conclusions

The following conclusions can be drawn from this study:

1. Channel blockage and delamination are not observed during the respective flow and pressure tests conducted on all the five types of adhesives.
2. 3M 8212 shows the highest peel strength, and hence the maximum handling strength among the five types of adhesives tested.
3. Variation in channel width has no effect on the amount of adhesive sagging into the channel when the size of the channel is less than 1300 μm.

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