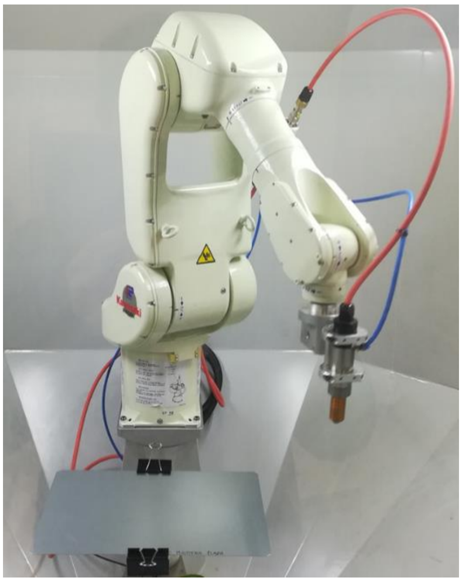
# Enhancing bonding properties of pressure-sensitive adhesives on white goods by means of atmospheric-pressure plasma treatment

Corinna Little, Dariusz Korzec, Dominik Burger, Stefan Nettesheim
relyon plasma GmbH, Regensburg, Germany

**Abstract:** The improvement of the adhesion of different pressure sensitive adhesives (PSA) on differently coated steel sheets by atmospheric pressure plasma jet (APPJ) treatment is investigated. Two types of APPJ have been applied: the pulsed atmospheric arc (PAA) based 700 W industrial device and 18 W piezoelectric direct discharge (PDD) based handheld plasma brush. The first is used for surface activation of coated steel sheets. The second – for treatment of the PSA layer on different adhesive tapes. The adhesion force is determined by a 90° peel strength test. It is more than doubled, if the PSA surface is treated as compared to an untreated PSA on a pre-treated substrate and partially cohesive failure is reached. Despite of an increase in surface energy after plasma treatment of the coated steel sheets, the adhesion force was only marginally increased and adhesive failure occurred with untreated PSA.

**Keywords:** plasma, PSA, adhesion, APPJ, atmospheric pressure plasma, piezoelectric



## Introduction

Major appliances have taken on an important role in our lives and in our homes. Not only are they expected to be reliable and efficient, but also to be stylish and to canvass for its respective brand. Logos and embellishments are therefore applied to these products by many manufacturers, oftentimes by means of pressure-sensitive adhesives (PSA).[1] However, a high quality of the bonding between the coated steel sheets and the pressure-sensitive tapes is not always possible without pre-treatment. In a highly automated production line, atmospheric-pressure plasma[2] is a convenient and cost-effective means of fine-cleaning and activating substrates in preparation for adhesion processes with minimal to no effect on the throughput.

**Figure 1:** A robotic plasmabrush PB3 system with fixed steel sheet ready for operation.

It is frequently used for improvement of the adhesion of PSA on different surfaces. [3] Typically the material on which the PSA should adhere is plasma treated.[4] But a strong improvement of adhesion on steel has been observed, when the PSA (PIB – poly(isobutylene)) and PBA: poly(butylacrylate) itself was pre-treated by oxygen plasma.[5] The improvement of adhesion by pre-treatment by use of different types of plasma (APPJ, [6] corona[7], DBD[8]) for PSA based on natural and synthetic rubber, polyurethanes and acrylate is shown.[9] The aim of this feasibility study is the evaluation of the influence of plasma treatment by use of different APPJ on the adhesion force of different PSA coated tapes on coated steel sheets.

**Figure 2**: piezobrush PZ2 during activation of the PSA coated strip of foil.

## Experimental methods and materials

For this study two plasma tools with extremely different properties have been used: On the one hand the Pulsed Atmospheric Arc (PAA) plasmabrush® PB3 system, consisting of the plasma generator PG31[10] (shown with robot in Fig. 1) and powered from the high voltage pulse generator PS2000OEM and on the other hand the Piezoelectric Direct Discharge (PDD)[11] handheld instrument piezobrush® PZ2 (see Fig. 2). The main specifications of both tools are compared in table 1.

**Table 1:** Comparison in specifications of both plasma tools.

| plasma tool | **plasmabrush PB3** | **piezobrush PZ2** |
|---|---|---|
| operation principle | PAA | PDD |
| nozzle used | A450 | standard nozzle |
| plasma/consumed power | 150 W / 700 W | 8.3 W / 18 W |
| plasma plume temperature | hundreds of °C | close to room temperature |
| working gas | CDA | ambient air |
| gas flow | 50 SLM | 10 SLM |
| operation frequency | 54 kHz | 50 kHz |
| nozzle distance | 10 mm | 2 mm |
| typical activation speed | 1 m/s | 1 cm/s |

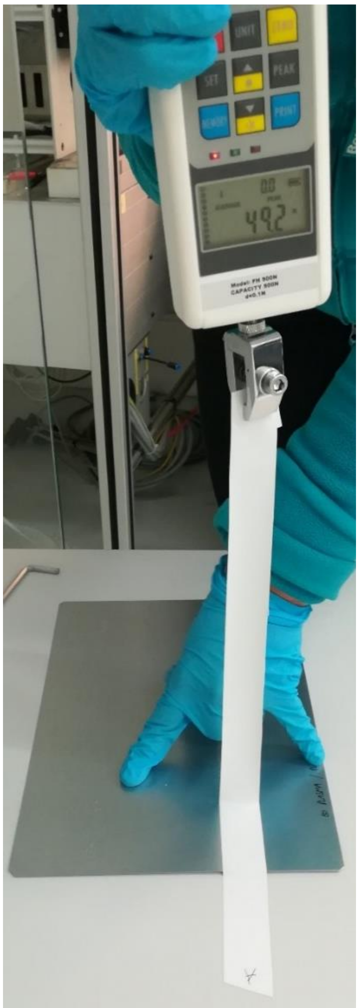


**Figure 3**: Conduction of the peeling strength test.

The plasmabrush PB3 can be used in two modes: diffusion plasma mode and focussed plasma mode. The second one is especially efficient for treatment of grounded metal surfaces. [12] But focus of this study are coated metal sheets. In such case the focussed plasma, working with arc transferred on the substrate could cause damage of the coating or weaken the interface between the metal sheet and the coating (varnish). Consequently, a less efficient diffused plasma mode has been applied.

A 6-axis robot Kawasaki RS05L (as shown in Fig. 1) has been used to move the PG31. The piezobrush PZ2 device has been moved manually.

### Test preparation

The 30 cm long, 25 mm broad strips of PSA coated foils have been placed on the steel sheet surface and fixed by use of a contact pressure roller. The force applied by the roller was 19.62 N.

The steel sheets with two different coatings have been investigated: Multiface® and CC enamel varnish. Three different PSA coated foils are used: Astorplast, Ritrama and Tesa. For plasma treatment with PB3 the process parameter as summarized in table 1 are used.

The 90° peel strength test has been conducted 20 min after strip fixing by use of dynamometer Sauter Model FH500N.

## Results and discussion

In the diagram in Fig. 4 the results of the peel strength tests are summarized. Each group of columns represent results for one PSA/coating combination. The first letter of the acronym under the diagram symbolizes the PSA-type, the other letters indicate the kind of coating. In each group of columns, the first column represents the peel strength for pristine surface and untreated PSA. The second column represents the peel strength on a surface cleaned with isopropanol only, which for some material combinations doubles the peel strength. Third is for surface treated with PB3 plasma generator only and in general shows only a slight improvement to the tests on pristine surfaces. The A-M combination shows 68% improvement when comparing with a non-treated sample, but is much weaker, than the sample cleaned only with isopropanol, while on the CC enamel varnished surfaces the effects of the PB3 plasma are comparable to cleaning with isopropanol. The fourth column refers to substrate which is cleaned with isopropanol and PB3 treated. The peel strength is in most cases comparable with results for isopropanol only. Finally, the fifth column represents the results for isopropanol+PB3 treatment, but additionally the PSA surface is treated by piezobrush PZ2. This step results in the most significant increase of peel strength for all combinations, which is for example more than doubling for A-M (Astorplast on Multiface coating).

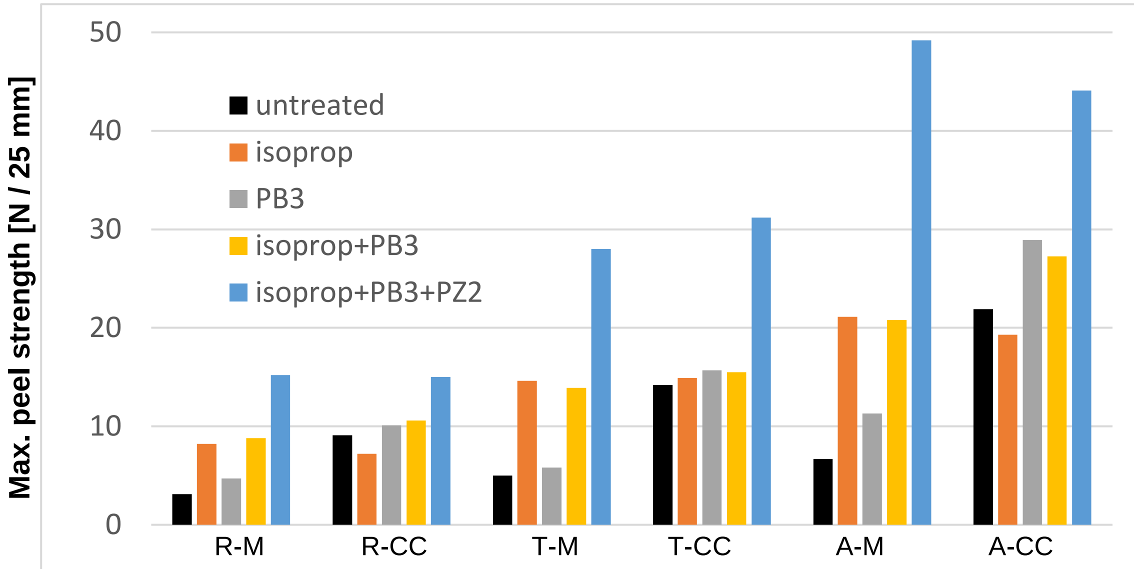
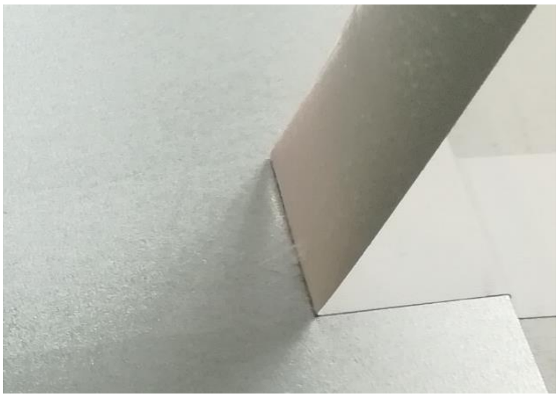



**Figure 4**: Maximum peel strength for three different PSAs (R, T, A) on two coating types (M, CC).



The plasma treatment of the metal sheets alone is not enough to reach cohesive failure. All PSA strips show adhesive failure on both substrates.

Due to the treatment of PSA on the strips, the adhesion force for Tesa and Astorplast material on both metal sheet coatings has been significantly increased and cohesive failure could be observed. The residua of the PSA can be seen on the substrate shown in Fig. 5.

**Figure 5**: Demonstration of cohesive failure on CC sheet after PZ2 treatment of Astorplast.

## Conclusion

- This feasibility study shows, that a Pulsed Atmospheric Arc (PAA) plasma system operated with compressed dry air, can help prepare the CC enamel coated steel surface by maximising peel strengths of certain pressure-sensitive tapes by up to 68% compared to the untreated substrate. The results are comparable to a cleaning step with isopropanol.
- Due to the high power density of the PB3 system a treatment speed of 1 $m^2$/min can be demonstrated.
- By treating the PSA coated side of the strips prior to bonding with a Piezoelectric Direct Discharge plasma, generated by piezobrush PZ2, maximum peel strengths can be doubled compared to the untreated PSA strips on pre-treated coated steel substrates. Compared to the untreated PSA on the untreated substrates, the maximum peel strength is increased over sevenfold.
- Two out of the three different types of plasma treated PSA strips show partial cohesive failure on both the Multiface and the CC enamel coated steel substrates whereas the untreated samples all failed adhesively.

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