NOVEL PSA FORM FACTOR FOR AUTOMATED BONDING

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Introduction

Double-sided foam tapes have been used in numerous applications and markets for over 40 years and have seen wide-spread adoption due to their high strength, durability, cleanliness during use, ease of bonding, and improved aesthetics of the finished part by eliminating unsightly mechanical fasteners. Foam tapes have been used to permanently bond metals, glasses, high and low surface energy plastics, and many others surfaces. Thanks to the ease of applying different adhesive skins on the top and bottom surface of the foam double-sided foam tapes are particularly adept at bonding dissimilar substrates.[1] Because of this versatility and successful track record, the standard foam tape form factor utilizing two adhesive skins coated onto a foam backing with a double-sided release liner (or tight/easy liner pair) has changed little throughout that time. Even the general handling of foam tapes via roll-to-roll die-cutting and converting processes has only made modest improvements in delivering level-wound rolls that are capable of some basic automation.

Automation and the accompanying digitalization of factories is a rapidly growing trend in numerous industrial markets: automotive, electronics, communication, appliance, and packaging; just to name a few. Many industry leaders and even several countries such as Germany's High-Tech Strategy 2020 and China's Made-in-China 2025 initiatives have embraced this 4th industrial revolution over the last 10 years.[2-3] It is clear that manufacturers and assemblers are looking to expand their use of automation to accelerate the rate of production and address pain points in their current processes. For existing adhesive dispensing operations these pain points arise from the complexity of handling traditional thermoplastic hot melts (e.g., long heated hoses, short open times) and liquid adhesives (e.g., mixing ratios, low viscosity induced sagging, purge waste), limitations on part design (e.g., planarity, stand-offs, narrow gap tolerance), and inflexibility in bonding processes (e.g., fixturing, curing stations, humidity control).

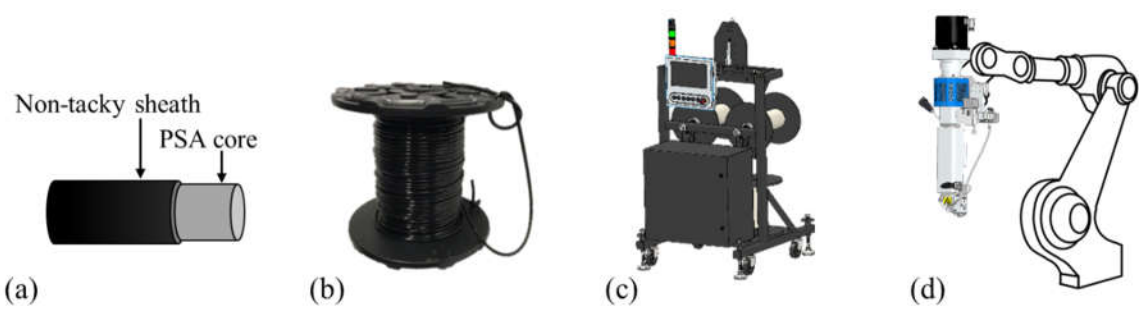

Figure 1: Schematic of the novel PSA form factor, adhesive spool, feeding system, and dispenser.

Recently, our team has reimagined the traditional tape form factor into a core-sheath filament (Figure 1a) that consists of a pressure sensitive adhesive (PSA) core and a non-tacky sheath material. This PSA filament can be coaxially coextruded and subsequently wound into spools of adhesive (b) that are easily

delivered to customer sites. This new form factor has been seamlessly integrated into an automated adhesive delivery system that feeds the filament (c) into a dispense head mounted on a robotic arm (d) which melts and masticates the core-sheath filament before directly applying it to the target substrate as a hot melt PSA. This convenient filament dispensing system has a small equipment footprint, nominal maintenance costs, requires minimal to no surface preparation or purging, and requires a relatively low capital investment. This creates automation opportunities for installation at smaller scale assemblers or for retrofitting existing manufacturing lines that were previously unavailable.

This new adhesive retains its PSA character after cooling which allows for the versatility of automated liquid dispensing while also enabling the extreme open times and viscoelastic character of traditional tapes. PSA performance is typically evaluated in terms of peel, tack, and shear which arises from the complex interactions of bulk rheology and substrate interactions (e.g., chemistry, interfacial contact, tribology, etc.).[4-8] Given the importance of peel and shear in the bonding and joining industry, this work looks to compare the bond formed from this novel PSA under different aging conditions, substrate types, and on ribbed surfaces. To characterize the difference between the adhesive formulation and the act of direct hot dispensing of the PSA onto the test substrate, its adhesive performance was compared to an adhesive transfer tape (ATT) of identical composition and bonded at room temperature. Some commercially available foam tapes were also tested to benchmark against.

Results and Discussion

For the following experiments, the filament PSA was dispensed as a hot adhesive ribbon at 215°C with a smear nozzle directly onto the desired test panel resulting in a 45 mil thick and 0.5 inch wide PSA strip to which an anodized aluminum foil backing was immediately laminated for later 90° peel testing. Similarly overlap shear (OLS) samples were dispensed and prepared using a round nozzle and a metal jig designed to keep the overlap area to 1 inch wide by 0.5 inch long and a control gap of 45 mil between the test panels. The ATT control was prepared using a small twin screw extruder to melt and mix the same PSA filament and subsequently coat a tape 45 mil thick and 5 inch wide onto a double-coated release liner. The ATT was cut from this wide format tape into test strips 0.5 inch wide for peel and OLS testing. Double-sided foam tapes were similarly cut into 0.5 inch test strips as comparative examples.

Figure 2 compares the 90° peel performance of the hot dispensed PSA (HDPSA), an adhesive transfer tape of identical composition bonded at room temperature, and three commercially available foam tapes (FT) on five different commercially relevant substrates: polypropylene (PP), stainless steel (SS), anodized aluminum (Al), polycarbonate (PC), and glass. FT-1 represents a stiff foam, FT-2 a soft foam, and LSE-FT is a medium stiffness foam with adhesive skins tailored to bond to low surface energy (LSE) substrates.

The 90° peel values of all the PSAs in Figure 2 are remarkably high and it is noteworthy that both the HDPSA and laminated ATT was comparable to the high-performance foam tapes on all substrates. When examining the HDPSA peel on different substrates, the polypropylene adhesion stands out as the most impressive as only the LSE-FT is comparable to the filament adhesive. This phenomenon of achieving high adhesion to low surface energy plastics is clearly a result of the hot bonding process as the HDPSA has ~3 times the peel strength to polypropylene (29 Dyne/cm) compared to that of the ATT which was bonded at room temperature. A similar, although more modest (~2x), increase is also observed on polycarbonate, which is a medium surface energy plastic (42 Dyne/cm)[9].

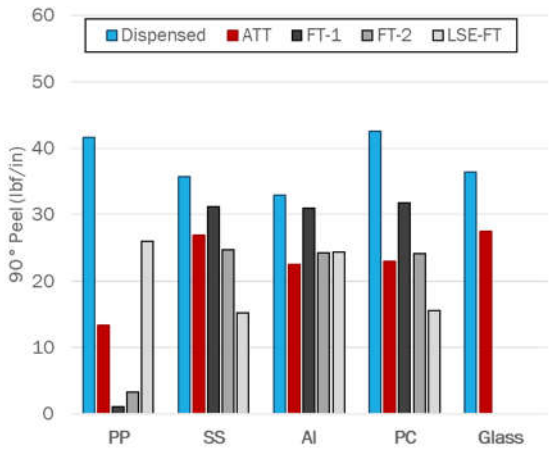

Figure 2: 90° peel results of hot dispensed PSA, an adhesive transfer tape of identical composition bonded at room temperature, and three commercially available foam tapes. Tested at 12in/min.

Figure 3 compares the performance of the HDPSA and ATT samples after five different aging conditions.

- *RT*: 72 hrs at 23°C and 50% relative humidity
- *Humid*: 168 hr 60°C and 95-100% relatively humidity
- *Hot*: 168 hr at 95°C
- *Cycle*: 24 hr at 95°C immediately followed by 96 hr at 35°C and 90% relative humidity immediately followed by 8hrs at 0°C
- *Cold*: 24 hr at -35°C

Samples were reequilibrated for at least 4 hr at 23°C and 50% relative humidity prior to testing.

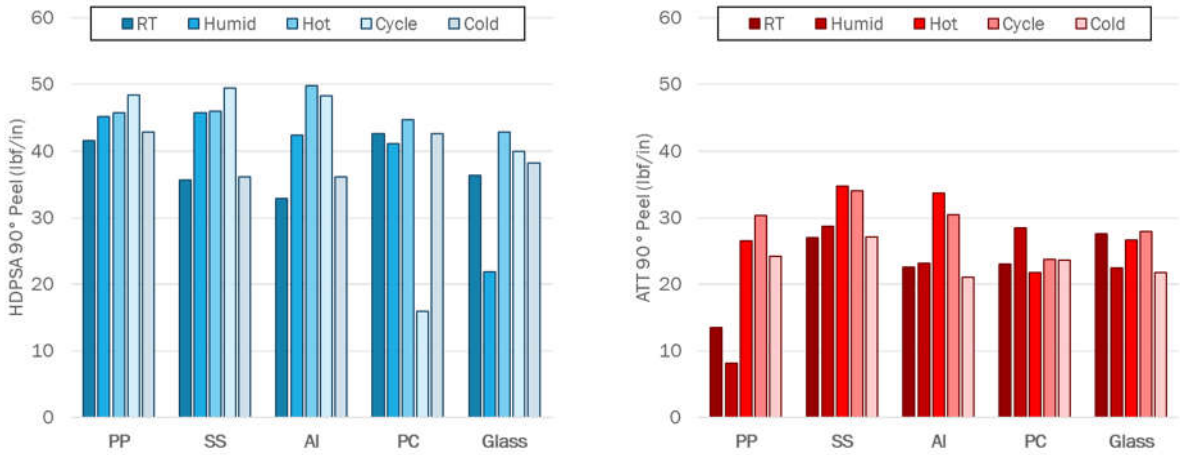

Figure 3: 90° peel results after different environmental aging conditions a of hot dispensed PSA (HDPSA), left, and an adhesive transfer tape (ATT) of identical composition, right. Tested at 12in/min.

As can be seen from the left bar chart of the HDPSA samples, the different environmental aging conditions generally have a neutral or positive effect on the 90° peel values. The high temperature aging of the Humid, Hot, and Cycle conditions led to a 20-50% increase in peel adhesion on the PP, SS, and Al substrates but no substantial improvements on the PC or Glass substrates. The Cycle aging condition on polycarbonate and Humid aging condition on glass resulted in a significant drop in the HDPSA peel force. Although the root cause of this decrease is unknown, it is suspected that the out-gassing from the polycarbonate substrate led to reduced interfacial contact and hence reduced peel strength. As a best practice, PC test panels are dried in a 85°C oven for at least 24hr prior to use to remove any adsorbed

water and to fully degas the polycarbonate but it is possible that untreated panels were accidently used in this test. The fact that there was seemingly no drop in adhesion in the Hot, Humid, or Cold aging conditions (similar to the three steps of the Cycle aging) makes this supposition very likely. With regards to the reduced HDPSA peel on glass after Humid aging, it is well known that glass's hydrophilic nature can cause water vapor to undercut an adhesive bond and interfere with the PSA durability. The use of silane coupling agents or a surface primer are common means to remedy this issue.

Now looking at the right bar chart of Figure 3, an improvement in peel force was also observed for the ATT from the Hot and Cycle aging conditions on SS, Al, and PP, but no statistically significant impact from the Humid aging. Despite a nearly 2x increase in peel adhesion on PP and a 30-50% increase on the metal substrates the ATT still falls far short of the HDPSA peel forces on these same substrates and aging conditions. The observation that aging for hours at 95°C in the Hot and Cycle environmental conditions was still insufficient to enhance the ATT peel results to that of the HDPSA was quite surprising given the identical composition of the two adhesives. Clearly there is an additional benefit to bonding at the very high dispensing temperatures of the HDPSA on the PP substrate.

To better understand how environmental aging might influence peel performance, the bond strength versus room temperature dwell time on a thermoplastic olefin (TPO) substrate was examined. Figure 4 shows the results of these peel tests (d), along with a proposed surface wet-out schematic. In the diagram (a) and (b) show how the ATT might initially have poor contact to the TPO surface but improve contact to the surface roughness with increased dwell times. It is believed that the HDPSA makes nearly full surface contact immediately upon dispensing (c) which is supported by the remarkably high and essentially flat adhesion results versus dwell time. The ATT demonstrates improved peel force after longer dwell times, which matches with common knowledge of increasing adhesive wet-out with increasing time.[10-12]

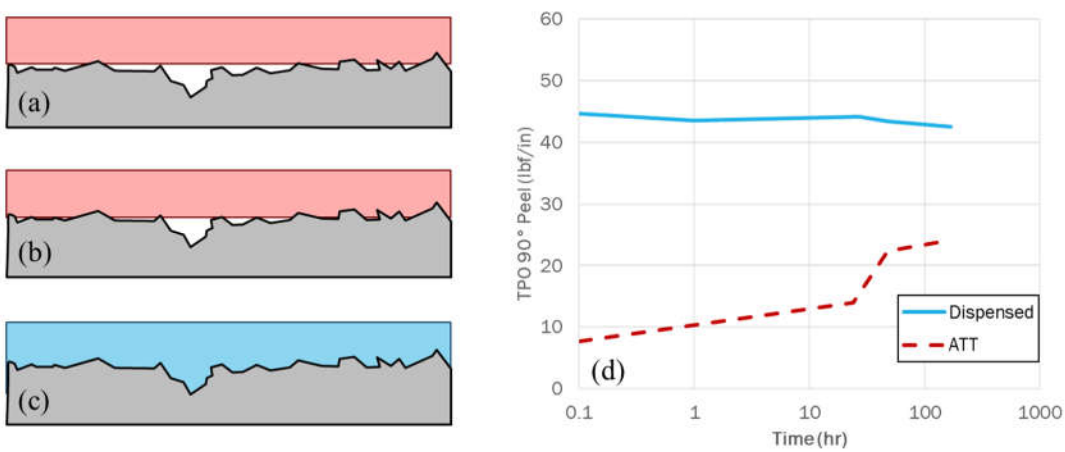

Figure 4: Schematic comparison of adhesive wet-out onto a test panel (a) immediately after lamination, (b) after some dwell time, (c) hot dispensing directly to the panel, and (d) 90° peel results from a thermoplastic olefine (TPO) substrate versus dwell time. Tested at 4in/min.

Figures 2-4 have shown a large difference between the HDPSA and ATT peel values on multiple substrates, after different aging conditions, and different aging times. Given the identical formulation of the HDPSA and ATT, the difference in peel values must be arising from the high dispensing temperatures (215°C) leading to a more intimate bond being formed by the HDPSA. Although enhanced interfacial interactions or molecular rearrangement within the PSA itself upon dispensing cannot be ruled out, the

increase in wet-out depicted in Figure 4 is the simplest explanation for the high peel values observed with the HDPSA and is unique to its dispensing process.

As was seen above, the HDPSA demonstrates a significantly increased peel strength relative to its ATT counterpart, however, Figure 5 examines the dynamic shear (also known as, overlap shear or OLS) of these two adhesives and shows a much smaller impact. There is still a large benefit to hot dispensing onto the polypropylene substrate and an improvement in the glass bonding but otherwise there is relatively equivalent OLS performance on SS, Al, and PC. This is a surprising result given that all samples failed via an adhesive failure mode and the HDPSA would be expected to have much higher peel strength to these substrates than the ATT. Additional research into the time to bond closure after dispensing, OLS failure mechanics, and the force necessary to form a good bond is on-going to better understand these results.

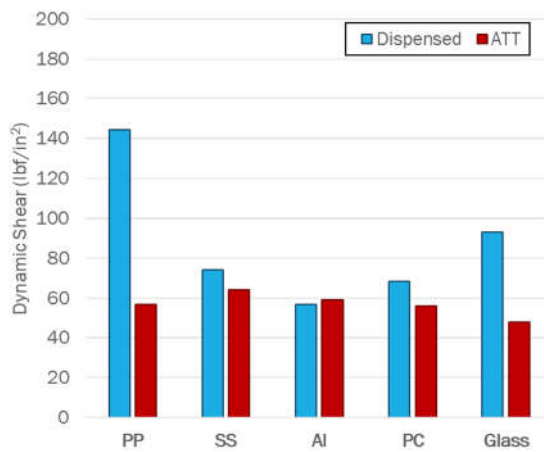

Figure 5: Dynamic shear results of a hot dispensed PSA and an adhesive transfer tape of identical composition bonded at room temperature. Tested at 2in/min.

Similar to the peel samples, overlap shear results were also investigated after different environmental aging conditions. Unlike the 90° peel environmental aging, Figure 6 shows a clear impact of high temperature aging on enhancing the OLS bond strength for both the HDPSA and ATT samples. This effect was much more pronounced for the ATT samples where enhanced OLS values were observed on all substrates under the Hot aging conditions and all but the glass substrate for the Cycle aging. The HDPSA also demonstrated enhanced OLS bond from the Hot and Cycle aging conditions and to a lesser extent the Humid aging condition as well which is also aged at elevated temperatures (60°C). Once again, the Humid aging on glass resulted in lower OLS values and could be addressed with the use of a primer or silane coupling agent. Overall, the HDPSA and ATT dynamic shear results were much more comparable after aging than was seen with 90° peel results, indicating that adhesive composition is much more impactful than initial bonding temperature in this test mode.

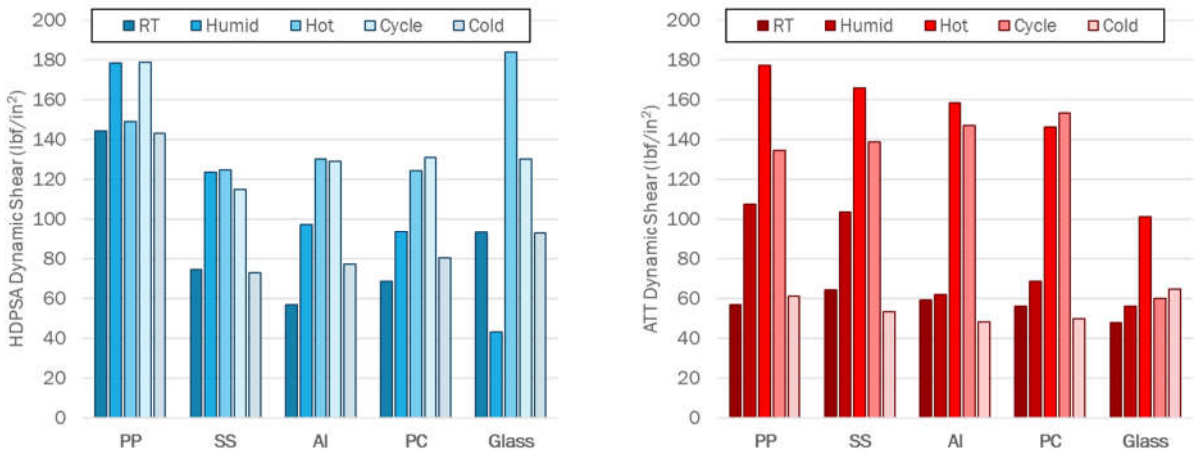

Figure 6: Dynamic shear results after different environmental aging conditions a of hot dispensed PSA (HDPSA), left, and an adhesive transfer tape (ATT) of identical composition, right. Tested at 2in/min.

Advantages of direct PSA dispensing

This novel PSA form factor and associated dispensing system allows for further simplification of the joining process through automation and the capability to bond dissimilar materials, irregularly shaped surfaces, and even enable gap filling (something not currently achievable even with large caliper foam tapes). Figure 7 demonstrates multiple ways of dispensing this hot melt PSA that enable additional benefits to the assembly process. (a) Smear nozzle dispensing of a PSA ribbon, (b) conical nozzle dispensing of rounded bead, (c) customizable stitching patterns to cover the same bond length but reduce adhesive consumption. One of the advantages of the smear nozzle, (a), is that you can make a 90° turn without having to rotate the dispensing head while maintaining a uniform ribbon profile leading to a gasketing seal. In additional to changing nozzles and the start/stop of the flow, the automated dispensing system also includes the ability to change the feed rate, the dispensing speed, and nozzle gap height, providing further controls that an operator can utilize to change both caliper and width of the final PSA.

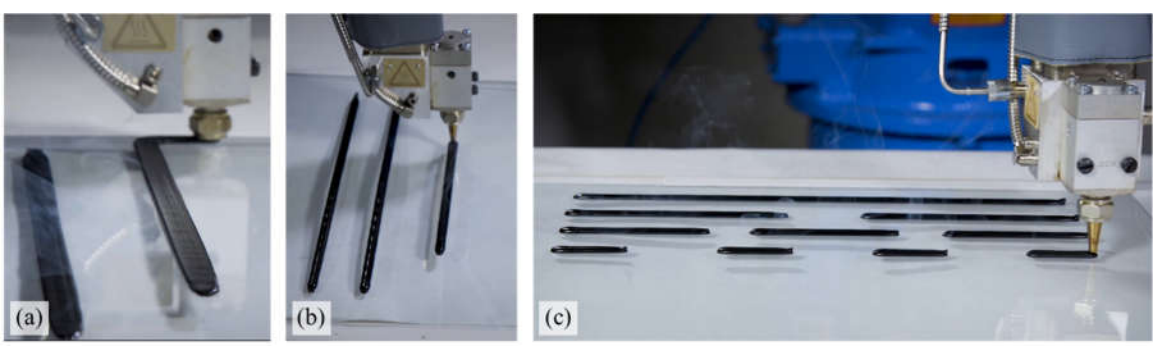

Figure 7: Dispensing of multiple adhesive bead widths, thicknesses, and stitching patterns.

Another benefit to hot dispensing of the filament PSA direct to parts is the capability to conform to irregular surfaces. An example of this is shown in Figure 8, where the adhesive bead is directly deposited on top of a highly ribbed surface (a) and is easily depressed into the troughs when the second substrate is applied to the top of the hot PSA bead (b) & (c). A similarly applied foam tape would have much more limited ability to compress into the grooves of the ribbed part resulting in much lower contact area and

peel force. The 90° peel value of the HDPSA, ATT, and as series of foam tapes (FT) were evaluated for their peel adhesion to a TPO ribbed panel (d). Not surprisingly the HDPSE had significantly higher peel force than all the other tapes even when the other tapes were nearly twice as thick or when primer was used (+P). Once again, the exceptional wet-out of the HDPSA to the substrate can be credited with enhancing its bond strength to such remarkable levels. The high conformability of the HDPSA upon deposition, while still maintaining a flat top surface, makes it an excellent choice for bonding warped parts or as a gap filler between parts with large tolerances.

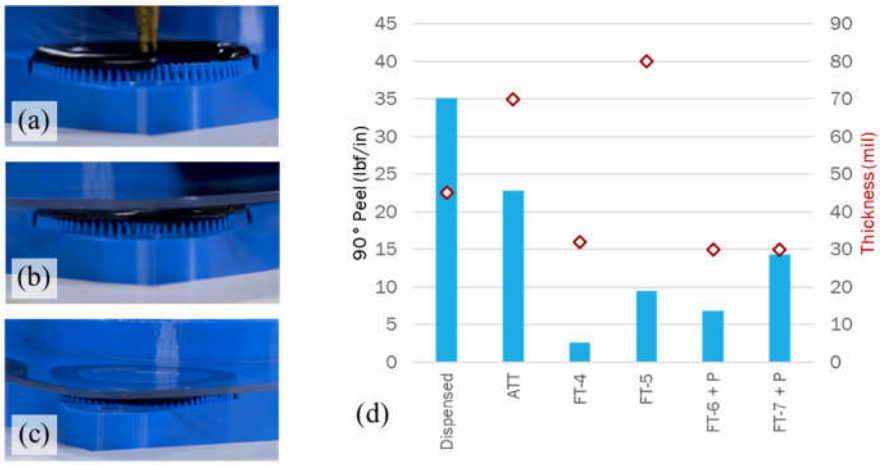

Figure 8: HDPSA dispensing onto, conforming against, and peeling from thermoplastic ribbed parts compared to foam tapes with and without primers. Tested at 12in/min.

Conclusions

Undoubtedly foam tapes will continue to be a staple of the bonding and joining market in the future as they have been for the last 40+ years. However, it is expected that the novel PSA form factor presented here will offer many opportunities to expand upon the foam tape market and accelerate the adoption of PSA automation. It can do so thanks to its remarkable adhesive strength that matches (or exceeds) the peel and OLS strength of existing foam tapes while seamlessly integrating into an automated delivery format. Some of the unique benefits of HDPSA use, like stitching patterns and ribbed part bonding, were also explored and show the HDPSA format is especially versatile as a bonding and joining solution.

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