FLEXIBLE ACRYLIC FOAMS: CARRIER FOR SPECIALTY TAPES AND BEYOND

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Abstract

Innovations in carrier films and foams have enabled the design of specialty PSA tape products for ever expanding end-use markets and applications. Foams are unique carriers because of their ability to absorb energy and damp vibrations. In addition, the conformability of foam substrates facilitates adhesion to irregular surfaces.

Acrylics have an inherent advantage in providing superior weatherability and durability properties versus many other polymer types. In this presentation we will illustrate a simple extrusion process to make flexible acrylic foams with a range of performance properties. With the ability to design and control cellular structures, mechanical and resistance properties of the foam substrate can be readily manipulated for various end-uses. We will also present advances made in some of the key technical challenges such as homogeneity of cellular structure, tensile-elongation balance, anchorage of adhesives on foam substrates and resistance properties such as water absorption and transport.

Introduction

Foam backed tapes have found use in a myriad of applications from industrial and automotive to consumer goods and health care. They are a sub-set of specialty tape segment with a healthy growth rate. Depending on the foam type, the value and growth rate varies considerably. Table 1 summarizes various foam tapes available in the market place and their end-uses.

<table>
<thead>
<tr>
<th>Foam Type</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Typical End-use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acrylic</td>
<td>UV resistance, durability, visco-elasticity</td>
<td>Cost</td>
<td>Mounting, Bonding, Sealing</td>
</tr>
<tr>
<td>(Syntactic foam)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polychloroprene</td>
<td>Soft, flexible, flame resistance, chemical resistance,</td>
<td>Adhesive anchorage, poor compression recovery</td>
<td>Gasket/Sealing, Weatherstriping,</td>
</tr>
<tr>
<td></td>
<td>insulation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PU (polyurethane)</td>
<td>Compressibility, low water vapor transmission, and low</td>
<td>Adhesive anchorage, UV resistance</td>
<td>Weatherstripping</td>
</tr>
<tr>
<td></td>
<td>water absorption</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PVC (polyvinyl chloride)</td>
<td>Soft, flexible, excellent compression recovery, inherent flame resistance, chemical resistance</td>
<td>Plasticizer migration, heat resistance</td>
<td>Gasketing, Weatherstripping</td>
</tr>
<tr>
<td>XL Polyolefin</td>
<td>Chemical resistance, low water absorption</td>
<td>Adhesive anchorage</td>
<td>Mounting, Window glazing, Gasketing</td>
</tr>
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</table>
Acrylic based syntactic foams are one of the faster growing segments; hence there is continued interest to offer customers options for acrylic foam backed tapes.

Acrylic syntactic double sided foam tapes are widely available, led by 3M’s VHB\textsuperscript{TM} (very high bond) tapes. Unique characteristics of VHB\textsuperscript{TM} tapes are its viscoelastic nature (absorbs energy and relaxes stress), strength (replace rivets and other permanent fasteners), long term durability, and ability to bond and seal (100% closed cell, forming a tight seal for moisture, dirt and chemicals). These characteristics delivered by VHB\textsuperscript{TM} tape are unmatched by other foam carriers such as cross-linked (XL) polyolefin, polyurethane (PU) or plasticized polyvinylchloride (PVC).

**Technical Approach and Challenges**

Several attempts have been made to produce traditional (non-syntactic) flexible acrylic foam that combines the benefits of a flexible foam structure with acrylic chemistry. The versatility of acrylic chemistry enabling the design of a wide array of polymer structure and morphology, and the inherent properties of acrylics such as good weatherability, durability and bio-compatibility are difficult to match with other chemistries at a comparable cost/performance ratio.

Making flexible acrylic foam requires the use of acrylate monomers which results in a polymer with low glass transition temperature (Tg). Low Tg acrylic polymers are inherently tacky, and this represents a critical problem for foam construction since cells collapse irreversibly when the foam is compressed.

Acrylic foam-like double sided pressure sensitive tapes available in the market today are materials known as syntactic foam led by 3M’s VHB\textsuperscript{TM} tapes. They are produced by incorporating glass micro-balloons in pressure-sensitive acrylic co-polymer with radiation cured, non-filled acrylic adhesive on both sides. Another approach\textsuperscript{2} involves the foaming of acrylic hot melt adhesive (co)polymers with expandable polymeric micro-spheres. The microcellular structure is provided by the volatilization of the hydrocarbons inside the expandable micro-spheres while cell collapse is prevented by the polymeric shell of the micro-spheres.

Both the technical approaches noted above resolve the cell collapse issue, but the process is complex and expensive. In addition, the resultant foams obtained are tacky limiting their primary use to adhesives tapes. Thus a need still exists for flexible acrylic foam that is not inherently tacky and can be used for a broad range of applications. A non-tacky flexible foam material further provides the opportunity to coat different adhesives on two sides making the construction more practical for bonding dissimilar surfaces viz. plastic and metal.

The present work solves the problem of cell collapse by providing a foam composition that is 100% acrylic based and imparts substantially improved mechanical properties unmatched by other foam backings. These improved mechanical properties enable the foam to be useful for several applications beyond the ones traditionally served by foams typically used in pressure sensitive foam backed tapes. An object of this work is to highlight the unique properties and inherent advantages of Resilient Acrylic Foam Technology (RAFT).
Resilient Acrylic Foam Technology (RAFT)

The preferred process (extrusion, injection molding etc) for making foams depends upon the polymer and the shape of the final product. The scope of the present work is focused on flat-die extrusion commonly used for PVC foam and is also known as free-foam extrusion. In the free foaming process the polymer melt expands freely upon exiting the die, as shown in Figure 1.

RAFT formulations are prepared by blending the proprietary acrylic polymer compositions in standard mixing equipment such as Henschel mixer, Banbury mixer, V-type mixer or a ribbon blender. The resulting blend can be processed in a single-screw or twin-screw extruder as a sheet. Figure 1 illustrates the schematic of the RAFT process.

![Diagram of RAFT Process](image)

**Figure 1.** Schematic of Resilient Acrylic Foam Technology (RAFT)

The gaseous phase of the acrylic foam can be provided by the decomposition of either a chemical or physical blowing agent. Typical chemical blowing agents include azo-, carbonate-, and hydrazide-based molecules. Alternatively, physical blowing agent may be introduced into the polymeric material as a gas, liquid, or as a supercritical fluid. Choice of the physical blowing agents used will depend on the properties sought in the resulting foam articles. For the results presented in the next section, chemical blowing agent was used in the formulation in conjunction with the RAFT technology.

Results and Discussions

RAFT based acrylic foams were extensively characterized to understand their performance properties relative to other foams. Results and discussions presented under various sections are organized as follows. In section I, we discuss the fundamental physical properties of foam which dictate the
mechanical properties. Section II highlights the mechanical properties which correlate with potential end-use applications. The water absorption and MVTR characteristics of various foams are described in Section III. Increasingly, sound and vibration damping is becoming an attractive attribute, and we dedicate Section IV for that. Finally, we describe how various adhesives perform on RAFT foams.

I. Physical Properties of Foam

A. Cell Structure

Foams in general can be classified as an ‘open-cell’ or ‘closed-cell’ structure. The cell structure determines the principal applications for such foams. Table 2 summarizes such applications.

Table 2. Cell Structures and their Principal Applications

<table>
<thead>
<tr>
<th>Principal Applications</th>
<th>Closed Cell</th>
<th>Open Cell</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal Insulation</td>
<td></td>
<td>Acoustic Insulation</td>
</tr>
<tr>
<td>Buoyancy</td>
<td></td>
<td>Cushioning</td>
</tr>
<tr>
<td>Packaging</td>
<td></td>
<td>Filtration</td>
</tr>
<tr>
<td>Gaskets</td>
<td></td>
<td>Packaging</td>
</tr>
</tbody>
</table>

In general, flexible foams tend to have open cell structure, however there are exceptions. The type of cell structure is determined by the method of expansion, and some materials can be foamed by more than one method to make either open- OR closed-cell structures. The cellular structure and the geometry of the cells in foam’s matrix influence its mechanical properties as we will see in the latter part of the paper.

Foams can also be classified based on the cell size and density. There are three broad classifications as follows:

1. Conventional $\rightarrow$ Cell Size $>$ 300 micron ($\mu$)
2. Fine-celled $\rightarrow$ 10 $\mu$ < Cell size < 300 $\mu$
3. Micro-cellular $\rightarrow$ Cell size < 10 $\mu$

One of several challenges while developing RAFT based foams was to obtain stable cell structures. Figure 2 characterizes the cell size of RAFT based foams. We have been successful to obtain stable foam structures. Based on the classification noted above, most of the foams listed in Figure 2, including RAFT based foams, would fall under ‘fine-cell’ foam category. It has been shown in literature that as the cell size decreases, there is a corresponding increase in tensile strength, elongation, tear strength, and resistance to compression.$^2$
B. Density

The density of the foam defines the fraction of each phase present (solid to void or air ratio). Density is also one of the key variables determining the physical properties of foams. Based on the density, foams can be classified as shown in Table 3.

**Table 3. Five Classes of Plastic Foams Based on Density**

<table>
<thead>
<tr>
<th>Type</th>
<th>Density (g.cm(^{-3}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Light</td>
<td>&lt; 0.05</td>
</tr>
<tr>
<td>Light</td>
<td>0.05 – 0.2</td>
</tr>
<tr>
<td>Medium</td>
<td>0.2 – 0.5</td>
</tr>
<tr>
<td>Heavy</td>
<td>0.5 – 0.7</td>
</tr>
<tr>
<td>Very Heavy</td>
<td>&gt; 0.7</td>
</tr>
</tbody>
</table>

Syntactic foams are usually higher in density when compared to other foams. One of the short term objectives of our work was to lower the density of RAFT foams when compared to syntactic acrylic foam. We have been successful in lowering the density to 0.5 g.cm\(^{-3}\).
II. Mechanical Properties of Foam

A. Tensile Strength and Elongation

*Tensile strength* is the ability of a material to resist breaking under tensile stress, and is one of the most important and widely measured properties of materials used in structural and semi-structural applications. The force per unit area (MPa or psi) required to break a material is the ultimate tensile strength or tensile strength at break.

The ultimate *elongation* of a material is the percent increase in length before it breaks under tension. Ultimate elongation values of several hundred percent are common for elastomeric materials. It is highly desirable to design materials with high toughness. This requires both high ultimate tensile strength and high elongation, a combination not easy to achieve.
Figure 4. Tensile vs Elongation at break (i.e. ultimate deformation)

Figure 5. Tensile vs Elongation at yield (i.e. reversible deformation)
Figures 4 and 5 demonstrate a unique feature of RAFT based foams. The syntactic foams in Figure 4 exhibit the greatest elongation but foams stretch to dimensions that are permanent deformation. The same experiment repeated in Figure 5 captures the % elongation at or just below the yield point. Interestingly, RAFT based foams fully recover their initial dimensions and do not exhibit any residual deformation even after 300% elongation. The unique elastomeric recovery behavior is not encountered in other foam technology viz. PO, PU and syntactic foams. This is attributed to the novel design of the proprietary RAFT foam formulation. This highly reversible elastic behavior, unique for RAFT based foams enables access to unexplored market opportunities and applications.

B. Compression Set and Compression Load Deflection

Compression set under constant deflection method covers the deflection of the foam under a compressive force under specified conditions of time and temperature, then noting the effect on the thickness of the specimen after releasing the compressive force. Compression set is expressed as a % of the original thickness, $C_s$. With the RAFT based foams, we can design a range of compression set, and more importantly we are successful in achieving very low, desirable $C_s$ values of < 5%.

Compression properties

\( \text{ASTM D1056 & ASTM D3575} \)

![Compression properties graph](image)

**Figure 6.** Comparison of Compression Set

 Compression load deflection (CLD) is related to the toughness of the foam and measures the force required to produce 25% compression. With the RAFT based foams we are able to develop very tough
III. MVTR & Water Absorption Properties

Water absorption and transport characteristics are important metrics when determining suitable applications for various materials in general. In some applications it is highly desirable to have minimal water absorption, especially if the application requires water sealing. In contrast, there are applications where it is necessary to have adequate transport. For example in a variety of medical applications, moisture vapor transmission is a key consideration when designing products. This property is identified as ‘Moisture Vapor Transmission Rate’ or MVTR. The figures 8 and 9 characterize the RAFT based acrylic foams with other foams. Ability to design the substrate to control the absorption and transport properties provides another degree of freedom for product development.

![Water Absorption Chart](image.png)

**Figure 7. Water Absorption Chart**

As noted in Figure 7, RAFT based foams present very low water absorption characteristics, when compared to most other foams except for syntactic foam. This particular feature is due to the very low proportion of open-cells. XL-PO and Neoprene are known to be ‘closed-cell’ foam but still possess higher water absorption. PU foams on the other hand with completely ‘open cell’ structure and act like sponge materials.
IV. Sound Damping Properties

The automotive industry is transitioning from the OEM’s taking the role in the development of sound management to now having the suppliers be responsible for optimizing the sound package treatments (including testing). Automotive design engineers are constantly looking for cost-effective assembly solutions while minimizing NVH (Noise, Vibration, Harshness) problems. Double coated foam tapes are carefully designed to adhere to multiple substrates for NVH and anti-squeak and rattle applications. In addition, there are industrial applications where vibration damping is a required performance attribute to enhance structural integrity. In this section we have characterized RAFT based foams in conjunction with other commonly used foam substrates specifically for sound damping properties.
Sound damping properties for various foams were characterized by a vibrational cantilever beam testing (Oberst Bar) according to ASTM E756 method. The test method measures the composite loss factor $\eta_{\text{CLF}}$, which is directly proportional to the sound damping performance.

$$\eta_{\text{CLF}} = \frac{\Delta f}{f}$$

Equation 1

where:

$\eta_{\text{CLF}}$: Loss factor (tan $\delta$) of composite

$\Delta f$: Width of the frequency peak at 3dB from maximum value

$f$: Frequency at maximum value

**Sound Damping**

*ASTM E-756, Base Beam: 0.8 mm x 12.7 mm x 200 mm (240 mm total length),
Frequency Interpolation: 100Hz & 800Hz*

![Graph comparing RAFT with Syntactic Foams at two frequencies](image)

**Figure 9.** Compares RAFT with Syntactic Foams at two frequencies (low and high)

Equation 1 can be further expressed as follows:

$$\eta_{\text{CLF}} \cong A \frac{E_2}{E_1} \left( \frac{H_2}{H_1} \right)^2 \eta_2$$

Equation 2

where:

$\eta_{\text{CLF}}$: Loss factor (tan $\delta$) of composite

$\eta_2$: Loss factor (tan $\delta$) of damping material
$E_1$: Modulus of beam

$E_2$: Modulus of damping material

$H_1$: Thickness of beam

$H_2$: Thickness of damping material

$A$: Constant

Figure 9 compares sound damping data for RAFT foams with syntactic foams at two different thickness and density. It is interesting to note that at lower thickness and lower weight/area, RAFT based acrylic foams are superior in damping performance when compared to acrylic syntactic foams. Analysis of the data represented in Figure 9 in conjunction with the Equations 1 and 2 clearly show that the thickness and weight/area are key parameters influencing the sound damping performance. Unfortunately, most commercial foams available at similar thickness *viz.* XL-PO does not possess adequate weight/area to act as effective sound dampers.

The results above also highlight that the flexibility in acrylic chemistry provides additional degrees of freedom for product design to build sound management characteristics.

V. Adhesive Performance

Understanding the interactions between the carrier material and the pressure sensitive adhesive are critical in designing double-sided foam tapes. For example in semi-structural applications, the carrier material provides key performance attributes *viz.* viscoelasticity and vibrational damping critical for design considerations. Solvent borne adhesives have been predominantly used for designing foam tapes because of their superior performance *viz.* adhesion-cohesion balance and water resistance properties. But increasingly water based acrylic adhesives are making inroads into this segment.

**WB Acrylic PSA with RAFT Foams:**

**Adhesion Performance**

![Adhesion Performance Chart]

*Figure 10. Adhesion Performance of Waterbased PSA with RAFT Foams*
Figure 10 summarizes the adhesion performance (20 mins dwell time, 2 MIL coat weight) of waterborne acrylic PSA (WBA) on various RAFT foams with decreasing elongation property. The foams were reinforced during peel testing to minimize the impact of viscoelastic property of the foam on adhesion values. It is well known that the mechanical properties of the carrier foam impact the adhesion and anchorage performance. Interestingly, we are able to achieve good anchorage to foams with > 400% elongation. None of the failure modes were adhesive failure from backing (AFB). The failure mode with HDPE panels does change over from adhesive (A) to cohesive (C) at very high elongation values.

**Adhesion Performance: RAFT II Foam with Various Adhesives**

![Graph showing adhesion performance of different adhesives on RAFT II foam](image)

**Figure 11.** Compares different PSAs with RAFT II foam

Figure 11 compares the adhesion performance (20 mins dwell time, 2 MIL coat weight) of waterbased acrylic (WBA), solvent acrylic (SA) and solvent rubber (SR) PSAs on RAFT II foams. For all three adhesive types we obtained good anchorage, demonstrating the versatility of the RAFT based foam carrier. For SR based PSA we routinely observe foam tear (FT) an indicative of excellent anchorage. The high adhesion values from stainless steel (SS) substrates are attributed to cohesive failure mode (C).

**Summary & Conclusions**

Our ability to explore a broad range of acrylic chemistry in conjunction with proprietary formulation know-how enables the design of RAFT based acrylic foams with a wide range of properties. Figure 13 below summarizes the current state-of-the-art with RAFT based foams. The combination of mechanical properties and performance properties opens up opportunities for new foam tapes as well as products in other market segments.
Figure 12. Range of physical and mechanical properties for RAFT based acrylic foams

It is clear from the range of properties that RAFT based foams are well suited for specialty applications with tailored performance. More specifically, the combination of tensile and elongation balance, low compression set with high compression load deflection, and low water absorption with reasonable MVTR creates an unique class of foams for product design. In addition, the performance ranges available for acrylic based PSAs (aqueous or solvent based) combined with these acrylic carrier materials are almost infinite.

References

2. Gehlsen, M. D. et al., WO 2000/006637

Acknowledgments

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