Handheld Shock Control Design Guide

ROGERS CORPORATION

Cushioning in Handheld Devices:
Understanding Impact

The Challenge:
Protecting Handheld Devices from Cracks

The most devastating malfunction for a handheld tablet or smartphone is a crack in the display; it cripples the functionality of a device and degrades the user experience. To make matters worse, it happens all the time. In SquareTrade's November 2010 Smart Phone Reliability report, drops were the cause of 77% of all accidental damage to the smart phones. The paper goes on to point out that, "the likelihood of drop damage is directly proportional to the amount of glass on the device,"[1] which bodes poorly for tablet devices.

Fortunately, choosing the correct cushioning material will mitigate the risk of cracked screens in these devices. This guide is meant to help you select the proper impact protection materials for your handheld designs. It will cover a variety of tools and concepts including a clear and thorough definition of shock absorption, how cushions dissipate impact energy, and why PORON® materials are great shock absorbers for handheld devices.

What is a Shock Absorber?

A shock absorber is a mechanical instrument designed to mitigate damage, dissipate energy, and reduce peak forces caused by an impact. In cars, shock absorbers – also known as "shocks" – are large springs that reduce the vibration felt by the passengers within the vehicle. In cellphones and tablets, foams can act as shock absorbers when these fragile devices are dropped. The kinetic energy at impact, which is equal to the potential energy of the device when dropped, is a major factor to consider when choosing the best shock absorber for an application. The relationship between impact energy and potential energy is shown in equation (1), where m is the mass of the falling object, v is the velocity at impact, w is the weight of the object, and h is the height the object is falling from. The question is: how does this energy relate to choosing the optimal cushioning materials for handheld devices?

$$(1) \quad E = \frac{1}{2}mv^2 = wh$$

The first step in solving this puzzle is to put the kinetic energy of an impact in terms of the shape and size of the cushion being used. This term is commonly called U, which stands for impact energy density.

In formula (2), the two new terms A and T relate only to the cushion used to absorb energy; A is the area and T is the thickness of the cushion. In a majority of cases, the size of the gasket or pad is already determined by the time a material is selected for the design. In this case, because the dimensions of the cushion remain constant, U is proportional to E and is completely defined by drop conditions.

$$(2) \quad U = \frac{\frac{1}{2}mv^2}{AT} = \frac{wh}{AT}$$

How do Cushions Help?

The next factor to consider is how well the cushion can dissipate energy at impact. Cushioning experts use a term called cushioning efficiency, also known as J, to define this property. J is mathematically defined in equation (3), where G is the peak acceleration of the object in g's - the acceleration of gravity - T is the thickness of the cushion, and h is the drop height of the object[2]. Cushioning efficiency is similar to impact energy density in that it relates a property of an impact event to a cushion. In this case, that property is peak acceleration.

$$(3) \quad J = \frac{Gh}{T}$$

To describe J effectively, consider the analogy of a car stopping at a red light. If the driver sees the red-light far in advance of reaching it, he can gently press his brakes, bringing his car to a gradual stop. In Figure 1, this case is represented by the long flat line; the car decelerates at a constant rate, so the force the driver feels is spread out over time. If the light suddenly changes to red, the driver will need to abruptly stop. The bell-shaped curve describes the forces felt by the driver in this case, and the peak force is much higher.

A cushion works the exact same way. Generally, cushions have a J of about 3 to 6, so they act more like the bell-shaped curve in Figure 1. A perfect cushion allows the object to decelerate evenly over the time of the impact and the thickness of the cushion, greatly reducing the peak force. However, even an ideal cushion will not be able to reduce the force on the object completely; it will only be able to spread out the force evenly as the material compresses until it is fully compressed. Technically, a cushion with a J = 1 is impossible to create, but it is possible to get close to that perfect cushioning efficiency[2].
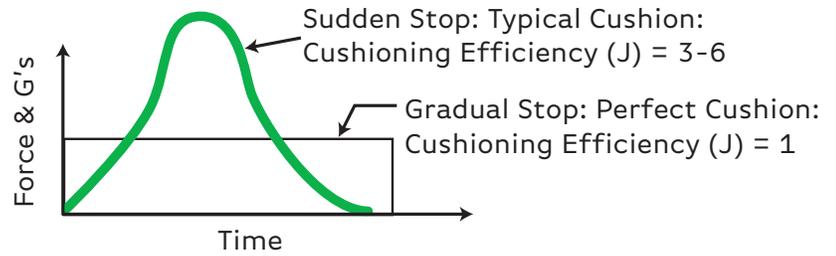

Figure 1: Force vs. Time curves depicting an object striking a typical cushion and a perfect cushion

How Well do PORON® Materials Perform at Cushioning?

The relationship between cushioning efficiency (J) and impact energy density (U) comes together in J-U Curves. These curves allow a designer to optimize material selection around impact performance. J-U Curves of many PORON Materials can be found on the Rogers High Performance Foams Impact Prediction Tool at http://www.rogerscorp.com/impactprediction. Figure 2 depicts J-U Curves for two different PORON Urethane materials, ShockSeal™ 79-12 foams and 92-12 foams:
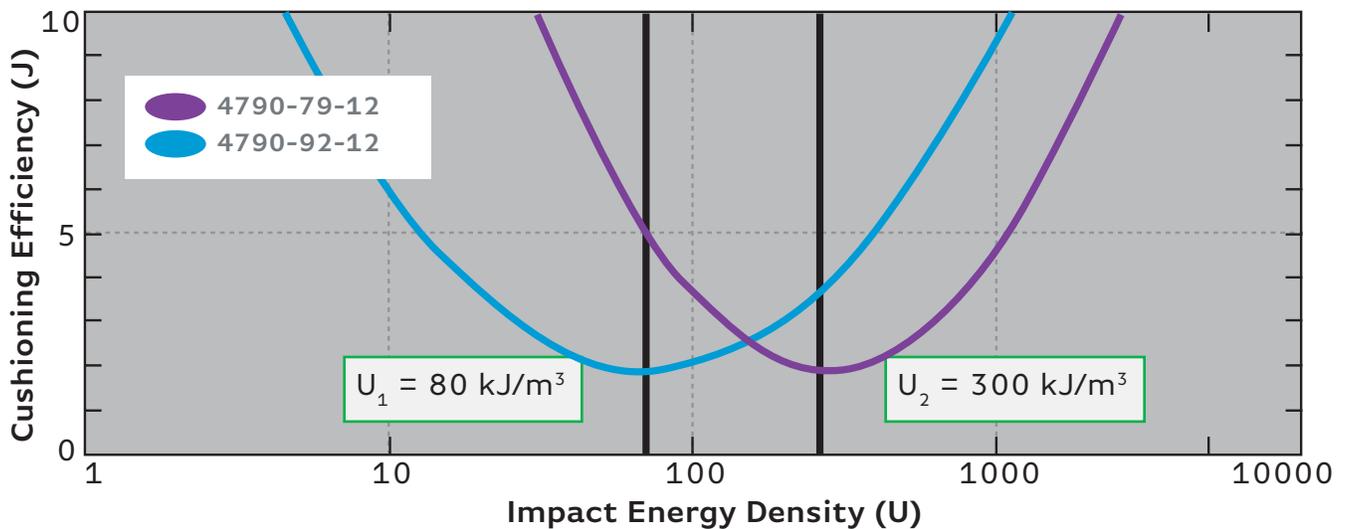
Figure 2: The J-U curves of two materials, 79-12 and 92-12. 79-12 materials cushion higher energy impacts better than 92-12 materials. Additional J-U curves of PORON materials can be found at http://www.rogerscorp.com/impactprediction.

The blue curve represents the cushioning capability of 92-12 materials compared to the energy density of the impact that needs to be absorbed; the purple curve represents the same concept for 79-12 materials. There are two drop conditions noted in figure 2, U_1 = 80 kJ/m^3 and U_2 = 300 kJ/m^3. Assuming the cushion in these phones is 1.0 mm thick and 8000 mm^2 in area (about the area of a large smartphone), U_1 is approximately equivalent to dropping a 125 g cellphone from 0.5 m, and U_2 is about equal to dropping that same phone from about 2.0 m. Figure 3 shows a Force vs Time graph of how both of these materials performed at these energy densities.

Compare these four curves in figure 3 to the two curves shown in figure 1. At U_1 = 80 kJ/m^3, the 92-12 material spreads out the force of the impact over time better than the 79-12 material. This is in agreement with the J-U Curve in Figure 2 because, at these test conditions, 92-12's cushioning efficiency is about 2 and 79-12's is about 5. On the other hand, at U_2 = 300 kJ/m^3 the 79-12 material spreads out the impact better over time, resulting in a J of 2. The flatness of 79-12's Force vs Time graph is interesting to note; it represents just how close to perfect 79 materials can behave in these drop conditions.
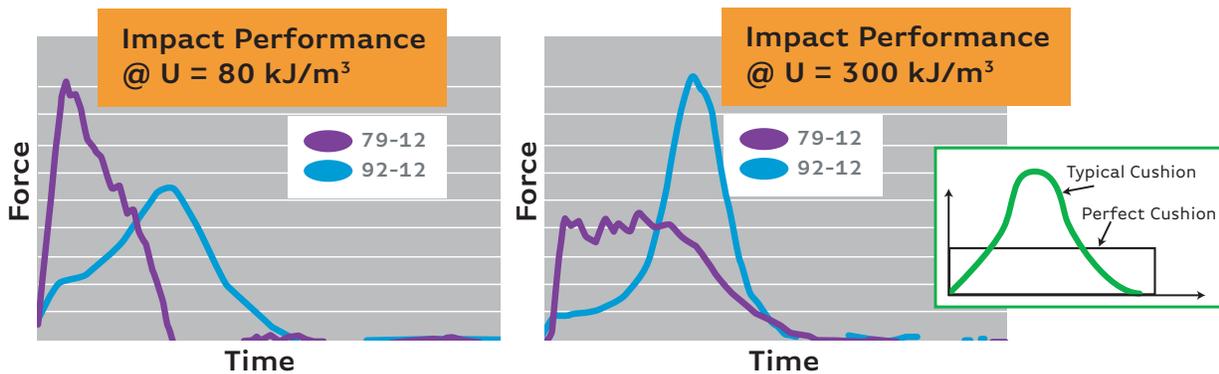

Figure 3: Force vs Time graphs of 92-12 and 79-12 at two different impact energy densities. In each case, the material which can more evenly spread out the impact over time results in a lower peak force. Finally, notice the flatness of the 79-12 curve at U-300 kJ/m^3. It infers that 79-12 behaves similarly to a perfect cushion in this drop condition.

4

The Potential of PORON Materials

CFD, or compression force deflection, curves are another common way to display the amount of energy a material can absorb. These curves represent the amount a material compresses when a certain force is applied. Figure 4 is a CFD curve of two PORON materials, 79-09 and 92-12.
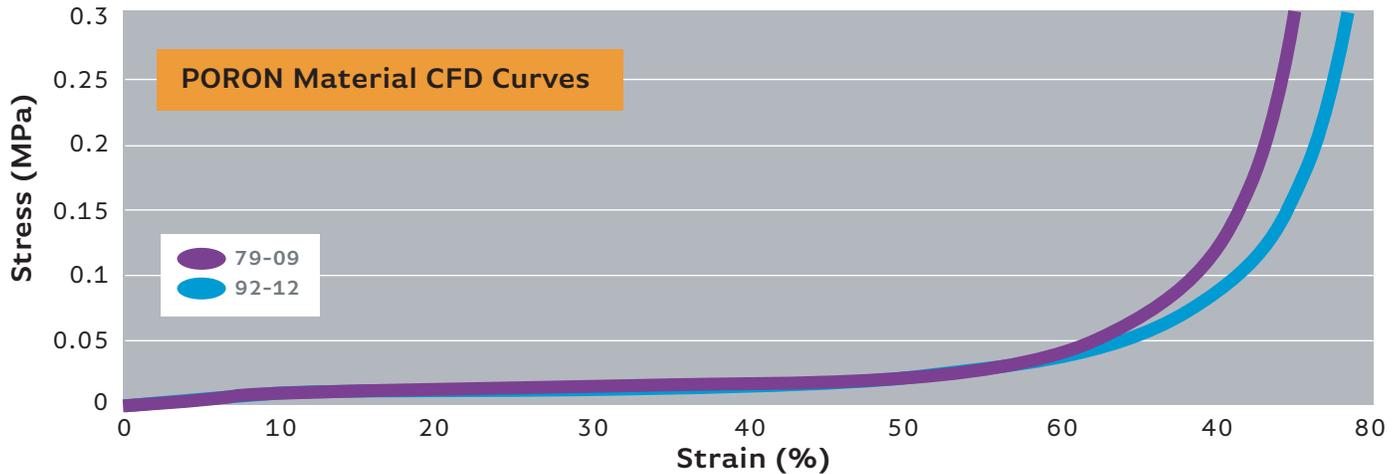

Figure 4: CFD curves of 79-09 and 92-12 materials

Given the area and thickness of the samples, the amount of energy a material can absorb during compression can be calculated. Figure 5 shows the results of this calculation, assuming a 1 mm thick sample that is 1140 mm^2 in area.
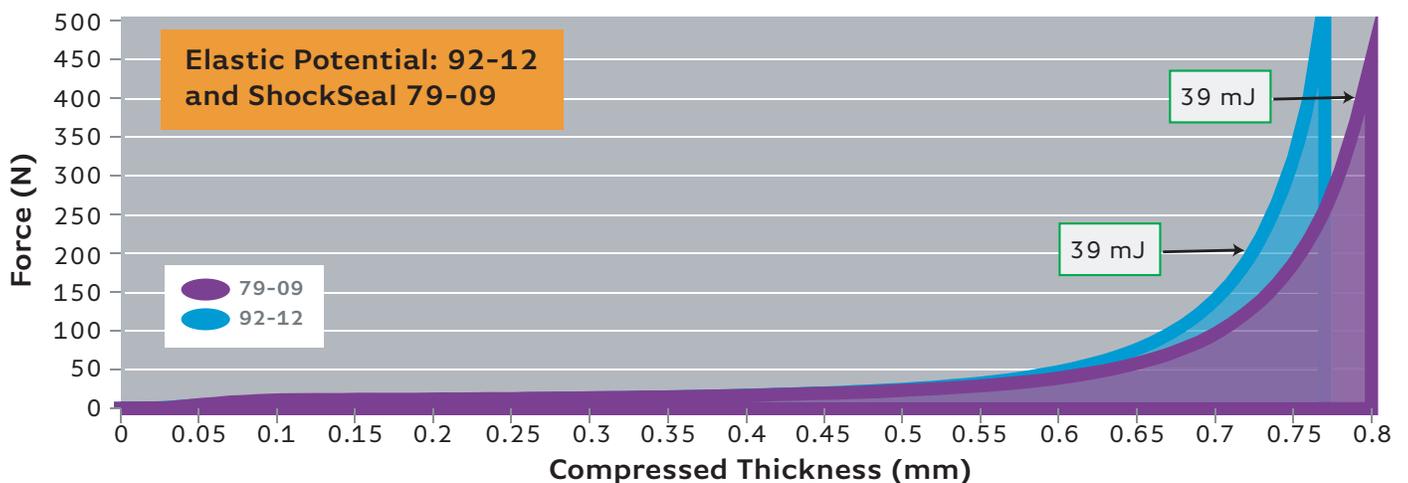

Figure 5: Compression Force vs Compressed Thickness. In this example, a 1 mm in thickness and 1140 mm^2 in area sample was used to calculate these values. These curves demonstrate the elastic potential energy of 92-12 and ShockSeal 79-09 foams.

Integrating the curves in Figure 5 results in the mechanical work, i.e. energy, used to compress the foam, shown in equation (4).

$$(4) \quad E = \int_0^T F \, dT$$

The elastic potential energy is the energy needed to compress the foam. What this means is that with the CFD curve, the amount of kinetic energy that a material can absorb during impact can be calculated. In order to dissipate all of the energy of an impact, the elastic potential energy of the material must be greater than the kinetic energy at impact, which is equal to the potential energy of the material as it is dropped. These outcomes are displayed in equation (5).

$$(5) \begin{cases} \int_0^T F \, dT \geq \frac{1}{2}mv^2 \longrightarrow \int_0^T F \, dT \geq wh \longrightarrow \text{Impact energy can be completely dissipated} \\ \int_0^T F \, dT < \frac{1}{2}mv^2 \longrightarrow \int_0^T F \, dT < wh \longrightarrow \text{Impact energy can only be partially dissipated} \end{cases}$$

According to the modified CFD curves in Figure 5, the elastic potential of 92-12 and 79-09 materials is 39 mJ. To put this in perspective, a 125 g cellphone dropped from 1.5 m results in an impact energy of about 1800 mJ. This would be bad news, but fortunately, PORON materials absorb a lot more energy than these curves suggest in an actual application. How? The strain-hardening of PORON materials comes into play.

6

Straining our Understanding

Cushioning efficiency is dependent on not only the energy density of the impact, but also the speed of that impact. Intuitively, this makes sense. A 20 g bullet traveling at 500 m/s would affect a cushion differently than a 100 kg wrecking ball traveling at 7 m/s, even though the energy

$$(6) \quad J = f\left(U, \ \frac{d\varepsilon}{dt}\right)$$

at impact for each of these objects is the same. A material whose cushioning efficiency alters as a result of a change in impact speed exhibits strain-rate dependence. A strain-hardening material, as the name suggests, hardens when compressed at a high strain rate. All PORON materials exhibit some level of strain-hardening , but two formulations in particular, 92 and 79, exhibit this behavior to a larger degree than any other PORON materials. It is no coincidence that these two materials are most often suggested for impact applications in handheld devices!

Before continuing further, once again we will relate a property of an impact and relate it to the cushion being used. $\frac{d\varepsilon}{dt}$, or strain rate, relates the velocity of an object at impact to the thickness of the cushion it strikes. Strain rate is defined in equation (7) where v is the velocity of an object at impact and T is the thickness of the cushion.

$$(7) \quad \frac{d\varepsilon}{dt} = \frac{v}{T}$$

For example, if an object strikes a 1 mm cushion at 1 mm/s, the strain rate of the impact is

$$\frac{1\,\frac{mm}{s}}{1\ mm} = \frac{1}{s}$$

Similarly, if an object is traveling at 2 m/s when it hits that 1 mm cushion, the strain rate is.

$$\frac{2\,\frac{m}{s}}{1\ mm} = \frac{2000\,\frac{mm}{s}}{1\ mm} = \frac{2000}{s}$$

A material's strain rate dependence can be evaluated with CFD curves measured at different strain rates. Although creating CFD curves at low strain rates is easy, creating them at high strain rates is difficult and expensive. Rogers has teamed up with an external lab to create high strain rate CFD data for a few products, including 92-12 materials and 79-09 materials, and the data is displayed in Figures 6 and 7.
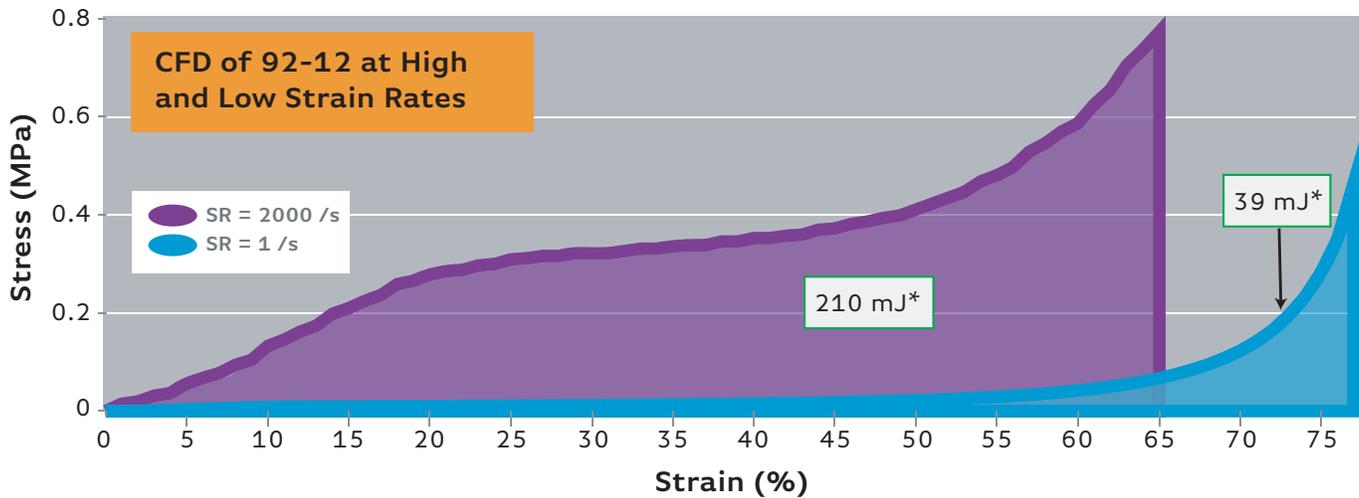
7

Figure 6: CFD Curves of 92-12 at two different Strain rates, at 1 /s and at 2000 /s. Notice that the area under the high strain rate curve is more than five times that of the area underneath the low strain rate curve.

Figure 6 shows the CFD Curves of 92-12 at two different strain rates, a high strain rate of 2000 /s (typical for a handheld device impact) and the original CFD curve shown in Figure 4 taken at 1 /s. It is clear that the high strain rate curve has much more area underneath it. If we assume the cushion is the same size as the example in Figure 5, when 92-12 is compressed at a strain rate of 2000 /s, its elastic potential is about 210 mJ, which is more than five times its original elastic potential of 39 mJ. While this is much better, it still falls well short of the 1800 mJ of energy caused by a 125 g cellphone falling for 1.5 m. In order to absorb this much energy, a PORON ShockSeal formulation material will need to be used.
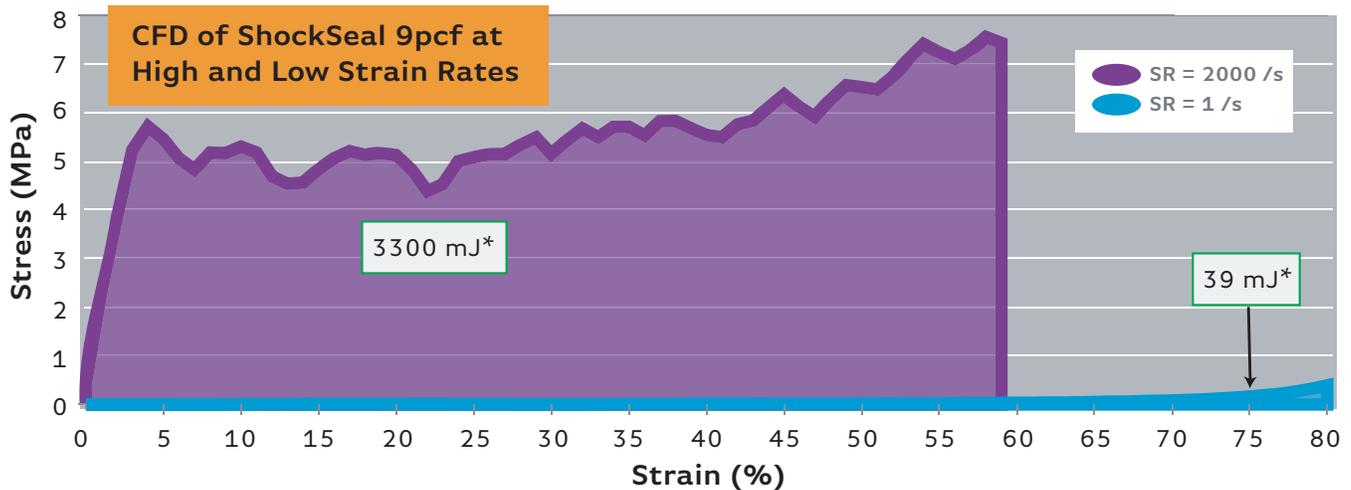

Figure 7: CFD Curves of 79-09 at two different Strain rates, at 1 /s and at 2000 /s. According to these CFD curves the elastic potential of 79-09 materials at 2000 /s is 100 times its elastic potential at 1 /s.

Figure 7 displays the incredible strain hardening of ShockSeal materials. Notice the order of magnitude increase in the stress values from Figure 6 to Figure 7. Also, compare the beginning of the high strain rate CFD curve in Figure 7 with the beginning of the force vs time curve in Figure 3 @ U = 300 kJ/m^3. They look very similar! Why? The exact same phenomenon is occurring. The strain-hardening ability of 79 materials allows it to dissipate impact energy over time (Figure 3) and allows it to absorb **more than 80 times** the energy when compressed at a high strain rate (Figure 7). At a strain rate of 2000 /s, 79-09's elastic potential is about 3300 mJ, more than enough capacity to absorb the 1800 mJ of a 125 g cellphone dropped from 1.5 m.

There are a few nuances to consider when using the elastic potential of a material to determine whether or not it is able to absorb all the energy at impact. First of all, this high strain-rate data is a best case situation. In the testing to create this data, a rod is used to crush the material at high strain rates until the material is fully compressed. In an application, the testing conditions are much less well defined, and application performance will vary with these impact conditions. These restraints reduce some of the elastic potential of the material.

Also, any firm material could be used to absorb the 1800 mJ of energy in the cellphone impact previously discussed. However, in order for a material to be used within hand-held devices, it must be soft and compressible so that it can perform other roles within the device, such as a gap filler and a dust seal. Because of this, shock absorbers within handheld devices must be soft during assembly and everyday use, but must become firm during impact. This type of strain-hardening behavior is what makes PORON ShockSeal and 92 materials the best shock absorbing materials for handheld devices.

Conclusion

Highly compressible materials are a requirement for handheld devices and the only way to provide impact protection with these highly compressible materials is to use a material that is soft in slow compression and is hard during impact, also known as a strain-hardening material. Only PORON ShockSeal and 92 formulation materials display this attribute to a high degree, and of those, only ShockSeal materials are capable of absorbing all the impact energy of a typical cellphone accident.

References & Notations

1. Squaretrade. "2010 Smartphone Comparison Study."
   http://www.squaretrade.com/htm/pdf/cell_phone_comparison_study_nov_10.pdf

2. Rogers Corporation. "Shock Control Design Guide."
   http://www.rogerscorp.com/documents/992/hpf/poron/industrial/Shock-Control-Design-Guide.aspx

* Assuming a 1.0 mm thick, 1140 mm^2 cushion is used

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