WHITE PAPER:

Common Questions on Polyurethane and the Polyurethane Molding Process

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Polyurethane and the molding process for polyurethane are complex subjects and contain many different and equally important variables. As the use of polyurethane in wheel applications has grown, several questions have popped up over and over again:

1. What is the importance of a proper bonding procedure?
2. How do you bond the urethane tread to the core?
3. What is the purpose of the Post Cure?
4. What is Durometer and how is this measured?
5. How is the hardness of the urethane controlled?

In this paper we will discuss these five questions and why each of the factors involved are important.

What is the importance of a proper bonding procedure?

As implied in the question itself, using a proper bonding procedure is indeed very important. When we talk about bonding, we are concerned with the interface between the urethane tread and the core (be it metal, plastic, or another material). Proper bonding ensures both the safety and longevity of the wheel, both of which go towards a business' bottom line. Employee injuries, inventory damage, and equipment damage cost both time and money and that adds up over time. Having to purchase wheels over and over does the same thing. So how does having a proper tread/core bond help with these issues? From a safety standpoint, a proper bonding procedure helps prevent the tread from separating from the core. This keeps the wheel operating as expected and employees, equipment, and inventory out of harm's way. In terms of longevity, poor bonding can lead to premature failure. Gaps and voids in the bond lead to extra internal flexing as a wheel turns. This extra flexing causes the local area to heat up faster and to a higher temperature than it otherwise would. That extra heat will begin to damage the wheel over time, potentially causing tread failure, separation via melting, or a breakdown of the polyurethane itself.

How do you bond the urethane tread to the core?

Now that we have established why bond is so important in a polyurethane wheel, we need to discuss how this bonding is accomplished. There are two types of bonds: the Mechanical bond and the Chemical bond. A mechanical bond is similar to how it sounds in that there is a structure built into the core of the wheel that extends into the polyurethane tread. Usually this structure contains an overhang to act as an anchor or pass through holes that will give the polyurethane something to flow through and around. Often times these two mechanisms will be used together. See Figures 1 and 2 for an example.

Figure 1. Example of a mechanical bond "pass through" hole.

As mentioned, the second type of bond is the chemical bond, which is often used in conjunction with a mechanical bond or simply on its own. This type of bond is achieved by applying an adhesive to the core prior to the wheel being cast and then casting the urethane over top. The bonding agent acts as glue between the core material and the urethane and improves the adhesion of the urethane by providing a layer of material that is much easier for the urethane to chemically react with and create a strong bond. As with most things, there are many different manufacturers of these agents and they all vary slightly in chemistry, but they all act in generally the same manner.

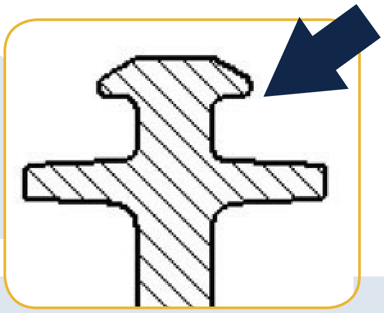

Figure 2. Example of an anchor shape.

What is the purpose of the Post Cure?

In its simplest form, cast Polyurethane is a two part material. These two parts are known as the prepolymer and the curative. On their own, they can be stored and generally used whenever they are needed. Without getting too deep into the chemistry of how urethane works, it can be simply said that when these two parts are brought together a chemical reaction begins. Polyurethane is generally cast at high temperatures in order to get the reaction to go as fast as possible so the wheel can be demolded in a reasonable amount of time, though there are other compounds out there that require different conditions. However, once the wheel is demolded, the reaction is still not complete. The post cure comes into play by continuing to provide the required heat to drive the reaction towards completion. In general, this takes several more hours at an elevated temperature (somewhere in the neighborhood of 200 degrees Fahrenheit) for the reaction to become complete. This is done by putting the wheels into racks and pushing them into a large, precisely controlled, pre-heated oven. Even with a post cure, the urethane will not reach its full capabilities immediately. The material's full capabilities can take up to thirty days longer to be achieved. During those thirty days, water from the air is pulled into the urethane. As this happens, the water reacts with the remaining isocyanate groups and allows the material to attain its maximum capabilities. This is why the post cure part of the process is so important. Without it, it would take much, much longer to reach the full capacity of the polyurethane.

What is Durometer and how is this measured?

Durometer is a type of hardness measurement. In the context of wheels, a Durometer rating allows us to quantify just how hard a polyurethane tread is. The particular scale used here was invented by a man named Albert F. Shore and is often referred to as the Shore Durometer Scale. Mr. Shore also invented a specific device, known as a Durometer, intended to test and indicate on his scale. Inside the scale are twelve individual subscales that cover a wide range of hardnesses. Typically there is some overlap on the scales. The Shore A and Shore D scales are primarily used when it comes to polyurethane wheels and are indicated with a numerical reading followed by the letter of the particular sub-scale. Some common examples would be 92A, as in the RWM Torus wheel, or 75D, as in the RWM GT wheel. Sometimes these values are indicated in a long form of 92 Shore A or 75 Shore D. Now, each scale has its own specific testing parameters and those parameters are laid out in the ASTM D2240 Standard. Here at RWM we have specifically calibrated testing units that follow these parameters and allow us to test our wheels with confidence. Below are photos of a typical set of Shore A and Shore D scale Durometers.

Figure 3. Shore A Durometer

Figure 4. Shore D Durometer

Each of these devices has a point on the bottom that is specified in the ASTM standard. To determine the hardness of a wheel tread, the point is pressed against the material and the gauge indicates where it falls on the scale. Each of the Durometers RWM uses is regularly checked with a set of calibrated gauge blocks to ensure accuracy.

How is the hardness of the urethane controlled?

Urethane hardness can be controlled in many different ways. The different hardnesses are generally achieved by using different prepolymer components as each type of prepolymer will generally have its own innate hardness. Beyond this there are ways to take a given prepolymer and adjust its hardness properties. Through the use of different curatives and additives the hardness can be raised somewhat (perhaps three to five points depending on the innate hardness). However, for the most part most adjustments in hardness are made downward and there are several ways to accomplish this. Some of the most common are:

1. Use a plasticizer. A plasticizer is a material that does not react with the polyurethane as it cures. It acts as a diluent material and makes the urethane softer at the cost of lowering the physical properties of the material. This happens precisely because the plasticizer does not react with the urethane.
2. Add another polyurethane base component. Some of the more common base components that get added to the formulation are known as a polyol, diol, or triol. These materials actually do react with the polyurethane. In this usage, they introduce long, flexible chains to the polymer. The addition of the long, flexible chains allows the material to be more flexible and thus softer. This method allows for a given base material to be altered quite a bit.
3. If you wish to drop the hardness a large amount, you can use a combination of the first two methods. Because a plasticizer is used, the physical properties will be reduced, however the effect is less than if the plasticizer method were used by itself.

But why is this important? We are all aware that different hardnesses of urethane are good for different purposes. A soft polyurethane wheel is good for noise reduction and shock absorption; though it's rolling resistance and load capacity will suffer. A harder polyurethane wheel will offer less shock absorption and noise reduction, but will have lower rolling resistance and a higher load capacity. The ability to tailor the hardness of a urethane wheel allows us to select the important properties and tailor a wheel for a certain type of application. By being able to manipulate a single type of polyurethane, it allows us to do more with that material and thus reduce the overall costs to our customers.

As mentioned before, polyurethane and the casting process are fairly complex subjects. Obviously each of the questions could have books written on just that subject, but hopefully this paper has managed to explain the general principles and give you a bit more knowledge on the subject.