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POLYURETHANE NON-PNEUMATIC TIRE TECHNOLOGY

POTENTIAL APPLICATIONS

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The polyurethane industry and its customers are rapidly becoming aware of the unique design and material possibilities which castable polyurethanes can yield. One example of the utilization of this materials and structural design relationship is a new technology for replacing solid, filled and pneumatic tires. This innovation is referred to as non-pneumatic technology (NPT) in the following pages, could well revolutionize the cast tire market. A history of the development of this technology and a listing of possible applications follows.

While the first solid tires did a fine job of carrying heavy loads, there was a certain lack of finesse in their design and formulation. Tree trunks and flat rocks were not always uniform. And thus, tire design came into being. As conveyance means transformed and animal born carts gave way to higher speed motor driven vehicles, solid tires evolved still further from steel banded wood wheels to elastomeric covered steel.

While these designs were satisfactory in their high load capacity, ride quality was lacking and various methods and designs have been incorporated to remedy this deficiency.

Of course, pneumatic tires have remedied the ride problem quite satisfactorily, but another annoyance crops up that has plagued motor driven vehicles since the pneumatic tire introduction: the flat tire.

In operations where downtime is extremely expensive, unacceptable, or even life threatening and pneumatic-type ride is desired, there are a number of tradeoffs.

Soft or low modulus materials may be used in solid tires at the expense of added mass or filled tires may be used to prevent the punctures of a pneumatic system.

But a new technology has been developed, which shows excellent promise for application in areas when the best of all performance parameters is required.

This technology which was first applied to automotive spare tire applications involves a unique blending of both design principles and material property characterization to eliminate the need for air.

This non-pneumatic technology involves an elastomeric tire body which may or may not require a rubber tread bonded to it. This "tire" portion is bonded to a metal wheel or ring typical in press-on operations. There are many advantages of a non-pneumatic system.

Since the tire is solid and contains no encapsulated or pressurized air, it cannot go flat, like pneumatics; or experience the runaway-type heat buildup for which foams are known. It is a maintenance-free system that cannot fail catastrophically.

In addition, it offers optimized material usage, yielding lower mass components and requires less cross sectional volume to carry similar loads than solids, filled, or pneumatic tires. The reduced mass provides for reasonable material economies and provides easier handling of the assemblies during transportation, and mounting to the hub.

An added benefit for the assembler and end user, especially over pneumatics, is that the NPT provides an integral unit. Thus the producer will supply a single item inventory, eliminating the need for handling separate tire, wheel and valves.

The material that constitutes the "tire" portion in our Non-Pneumatic system is truly a high performance elastomer. In combination with the design, deformations of more than 500% are sustained with the elastomer returning to its original shape. While we have developed an automotive spare tire incorporating a TDI-PTMEG/MOCA system, other polyurethane systems could be developed using the material requirements we have characterized as critical to optimum performance.

Cast polyurethanes are the only known material which can meet the rigid performance that this design and material partnership requires. The elastomer has to have superior "load carrying" ability, low heat buildup, excellent flex life and good tear resistance combined with long-term environmental aging and solvent resistance.

The exact mix of these material properties can have a dramatic effect on tire performance.

Tire durability is most important and is directly impacted by the elastomer's hysteresis and its resistance to flex fatigue. These two material properties affect the tire's high speed performance, its ability to handle overloads, and its overall mileage potential. Also affecting durability are adhesion both to the metal wheel and the rubber tread if used. Another durability issue concerns tire performance after years of aging, either in inventory storage or on little used equipment. Therefore, the polyurethane's resistance to aging in moisture, oxygen, heat and many other conditions is very important. Also, to be practical, the polyurethane must be easily processable. Other material properties important to this application include permanent set and temperature effects on modulus. Of course, from a commercial point of view, cost effectiveness is extremely important and can ultimately affect commercial success.

At varying stages of development of this non-pneumatic technology, certain aspects of the tire's performance were critical. The goal for material development of the polyurethane was to increase the "critical" performance without sacrificing other criteria. This "critical" performance may have been affected by more than one material property. Well designed experiments can usually determine the priorities for material improvement. Although tire tests are the ultimate tests for verifying material improvement; lab tests run at appropriate test conditions can speed material screening. However, standard physical testing is not always appropriate and special tests or test conditions may be needed for a specific application. These special tests can lead to dramatic tire improvement. A good example is flex fatigue.

Cut growth or flex fatigue can be measured on various laboratory testing machines. However, the user must know the strain energy in the deforming sample to assure the test strains are appropriate for the application. For this material development project we chose the Texus Flex machine. Basically, the polyurethane samples are molded with a hinge area, which is pierced and subjected to a bending cycle. The number of cycles needed for the cut to grow across the whole sample can be measured and used as the polyurethane's flex fatigue performance. To be of value, the testing must be done under conditions not far from those existing in the tire. Measurements in actual tires determined what strains and temperatures were appropriate. This test and its conditions were then verified by correlating with tire performance on laboratory test wheels, initially using off-the-shelf prepolymers. Once we saw the importance of flex fatigue on tire performance, we were able to develop new materials, screen them, and develop newer improved materials. These improved materials have dramatically increased the non-pneumatic tire's overall performance.

Flex fatigue is just one material property and a wheel test is just one type of measurement of tire performance. Improving one tire performance property without sacrificing other tire and material properties is a challenge. Constant stretching the boundaries of tire performance demands continued material development in all areas.

The elastomeric contribution is only part of the reason for the success of the technology to date. The design is also critical to take full advantage of the polyurethane's material properties. The design of the non-pneumatic tire is unique. It consists of two load carrying members, a web disc, and angled spokes which connect the inner and outer rings of polyurethane that are bonded to the wheel and tread surface.

These two load carrying elements support each other and provide a synergistic load capability; in other words, the tire's load capacity is much higher than the sum of the capacities of its individual unsupported load carrying parts.

This load carrying structure of the NPT exhibits the ride quality of a pneumatic tire. It is accomplished by a design, optimized through finite element analysis. This solid structure is capable of carrying high loads in high speed operations, yet has the unusual ability to deform to road surface irregularities, and obstacles by local buckling.

This is possible through a unique geometric relationship whereby the tire's overall spring rate is high, but its local spring rate, recorded when deflected over a line or cleated load, is low.

The optimization process we have employed involves a parametric finite element program where we can alter more than 15 design and material variables and conduct 2 dimensional and 3 dimensional analyses of the effects on principle stresses, strain energy density, load capacities, etc. This eliminated considerable time and expense in mold reworking and testing.

The beauty of this unique combination of design and material properties is that the technology can be adapted to many different load carrying applications with vastly different performance parameters. Application possibilities for which we see relatively short development time frames includes other non-spare automotive, trailer, and non-D.O.T. regulated automotive applications. Also possible are agricultural, material handling and industrial uses. Often overlooked, but highly probable fitments could also include those in aerospace and military wheeled vehicles. Virtually any application now using solid, filled or pneumatic tires which could be enhanced by a high load, higher speed, maintenance free and cost competitive alternative, are candidates for non-pneumatic technology.

In conclusion, this new non-pneumatic technology relies on a unique blend of design principles and polyurethane material properties. While still in its infancy, this development appears to be the next feasible innovation to displace many currently accepted tire technologies. It's full utilization will subsequently increase consumption of polyurethanes, polyurethane processing equipment, and related chemicals, and will surely enhance the image and viability of the polyurethane industry in the years to come. We hope it will also serve to increase the awareness and appreciation of the capabilities that can be realized through proper design and engineering with castable urethanes.