Carlisle TyrFil:

Comparing the Benefits of Polyurethane Filled Tires to Solid Tires

History: The Evolution Of Flatproofing OTR Tires

In 1844, Charles Goodyear patented the vulcanization process, which removed sulfur from rubber, making it waterproof and preserving elasticity.[1] Soon after, solid rubber tires were developed—a big improvement over metal, wood, or leather, but they provided a rough ride.

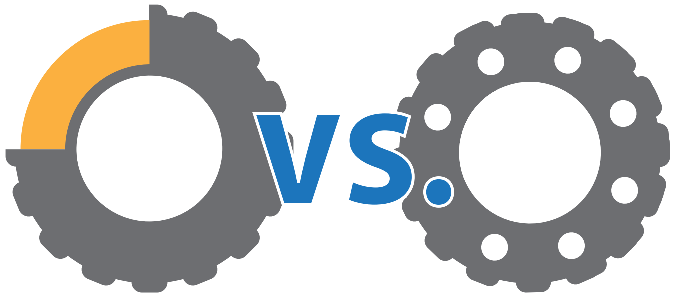
Use of solid tires continues today, primarily for OTR heavy equipment applications. There are several types—a 3-stage tire constructed with a more flexible center material that provides some level of deflection, a 2-stage tire made of one compound, pneumatic shaped solid tires of various construction, and a solid aperture tires with holes in the sidewall to provide some deflection. Lastly, certain solid tires are pressed-on and others are cured-on.

Pneumatic or air-filled tires were invented by Robert Thomson in 1845 and refined by John Dunlop in 1888.[2] They were a vast improvement over solid tires, providing a much smoother and more comfortable ride.

Polyurethane tires were introduced by Otto Bayer as a replacement for expensive rubber during World War II.[3] Polyurethane did not become a widely used flatproofing solution until 1971, when TyrFil™ was invented by ArncoPathway, now Carlisle TyrFil.

Tire fill is a polyurethane liquid that is pumped into pneumatic tires to replace air with a resilient, synthetic elastomer core that eliminates dangerous and costly tire flats in commercial and industrial heavy equipment vehicles. Tire fill is typically delivered through the valve stem and cures within 24 to 36 hours to offer excellent flat free protection. The material can be used in any tire with a sound casing and is able to sustain tire pressure and footprint shape —even in adverse weather conditions, including temperatures as low as 70 degrees below zero, or in sweltering heat.

This polyurethane tire fill material has seen many further developments and improvements in ride quality and endurance since then, and the continuous improvement of formulations and the filling process has allowed polyurethane filling to maintain its position as the preferred value proposition for eliminating flat tires. This value—and the performance track record that marks the advantages of using filled-pneumatics on heavy equipment used in off-the-road (OTR) applications is the reason that most tire customers continue choosing polyurethane-filled pneumatic tires for their needs.



Eight Performance Criteria

for choosing between these two flat free solutions

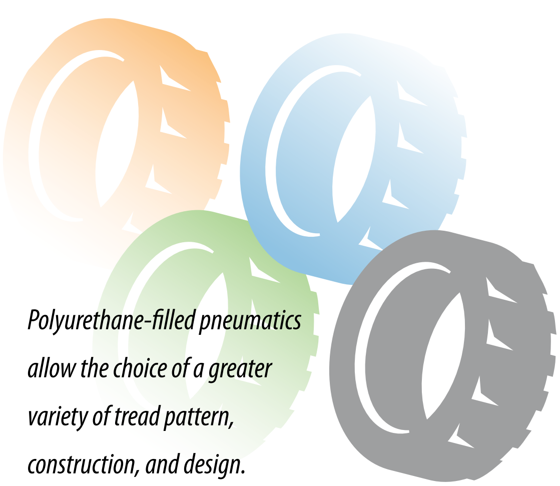
No matter what purchase decision we're making, we look for the solution that best fits our needs for the best value. Selecting flat free solutions for OTR tires is no different. Tire purchases and maintenance are among the most significant expenses that operators in the construction, waste management, mining, agri-business, industrial, and military fields must consider. The benefits of the two primary flat free tire options—1) polyurethane-filled pneumatic tires (commonly referred to as "tire fill" or "foam-filled" tires) and 2) solid or aperture tires—have been debated many times over the past few years by original equipment manufacturers (OEMs), aftermarket tire dealers, rental companies, and end users. It's important to understand that there is a healthy market opportunity for both products, and it can be difficult to compare the two in terms of constitution and performance. Both solutions eliminate flat tires and have other strengths and weaknesses when considering overall cost in use, impact to the operator, impact on equipment, maintenance and downtime, performance for each environment/application, and sustainability.

Determining the best option for your particular business and operational needs is entirely dependent upon the desired application. Both polyurethane-filled and solid tires will function effectively as long as they are installed correctly and used according to the manufacturer's instructions. The differences and considerations when selecting one over the other are evident in these eight performance attributes:

1. Adaptability And Choice

Solid tires are available in two main forms including 2-stage friction base tires, and 3-stage all-rubber tires. 3-stage solid tires provide a somewhat softer ride than a 2-stage because their middle is comprised by a softer rubber. Tread patterns for solid tires vary but are limited.

Any pneumatic tire can be filled with polyurethane tire fill and the composition of the fill itself can provide various performance characteristics. Polyurethane-filled pneumatics allow the choice of a greater variety of tread patterns, construction, and design (for example, smooth vs. lugged, radial vs. bias, and low profile vs. standard section height). The tire fill formulations that are available offer a range of physical properties including tensile strength, tear strength, elongation, deflection, compression, hardness, and rebound. Testing in the field and lab has demonstrated that these properties enable the tire to hold up at high speeds, loads, and temperatures. This means that tire fill creates a full range of choices for tire sizes, tread patterns, polyurethane fill durometers, and psi pressures. The equipment operator can then customize their tire fill solution according to each application with virtually endless combinations that cannot be matched by solid tires.

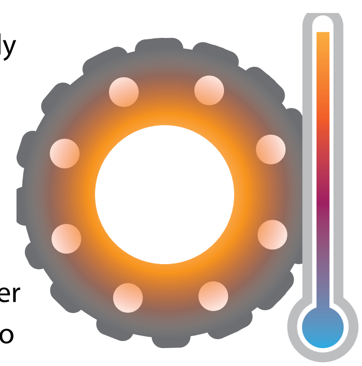


Polyurethane-filled pneumatics allow the choice of a greater variety of tread pattern, construction, and design.

2. Wear, Tear, And Durability

The life of a tire depends on many factors, including the application in which the tire is used, the quality of the tire, and whether the tire is used according to the manufacturer's specifications. However, the larger variety of tread patterns, sidewall constructions, and rubber formulations available when using polyurethane-filled pneumatic tires compared to solid tires allow the customer to customize the tire and fill for specific applications and surface conditions. This customization optimizes traction, comfort, and tread life, resulting in increased value. Moreover, the use of polyurethane tire fill ensures less vehicle damage due to prematurely worn out components as a result of lessened G-force transmission.

While solid tires have traditionally been associated as being better suited for use in some extreme applications such as demolition, solid tires tend to retain more heat than polyurethane-filled tires. Heat is retained in the center of the solid tire, which can lead to catastrophic tire failure.



3. Traction

Another difference between solid and polyurethane-filled tires is found in the traction of the tire, which refers to the maximum frictional force that can be produced between the tire and the surface without slipping.[4] Due to the wide range of tread patterns, rubber compounds, and polyurethane hardness, polyurethane-filled tires have better traction over a wider variety of surfaces and terrains. Filled pneumatic tires tend to have additional ground contact area when compared to solid tires, giving increased traction, braking, and tire footprint.

4. Cushioning, Stability And "Shock Resistance"

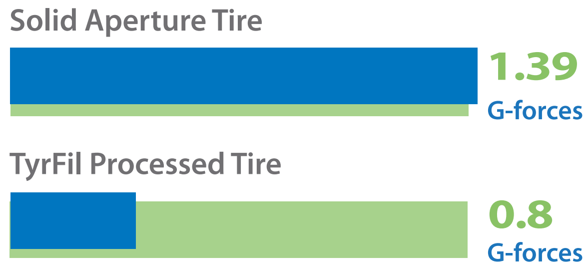
A significant measure used to evaluate the cushioning ability of any solid or polyurethane-filled tire lies in the "durometer" of the tire, for solid tires this would indicate the hardness of the rubber compound and other components used in construction of the tire, and in the case of filled pneumatic tires, in the polyurethane material that fills the tire cavity. A solid or polyurethane-filled tire with high durometer components is harder and absorbs less impact. A tire with low durometer components is softer and absorbs more impact.

Most solid rubber tires are manufactured with a two or three stage construction. They typically have a tread durometer of 65 and higher, with inner layers at high durometer levels. Many solid tires have added aperture holes in an effort to try and reduce the negative impact of a harsh ride performance, but these holes do not go through the entire tire and can easily crack. Newer elliptical or triangular designs have offset this cracking issue.

Polyurethane-filled pneumatic tires, on the other hand, offer a wider range of core durometers from 10 to 55, allowing the customer to tailor the deflection of the tire for the application. Additionally, the pressure the polyurethane fill is installed at can be specified to match the application requirements.

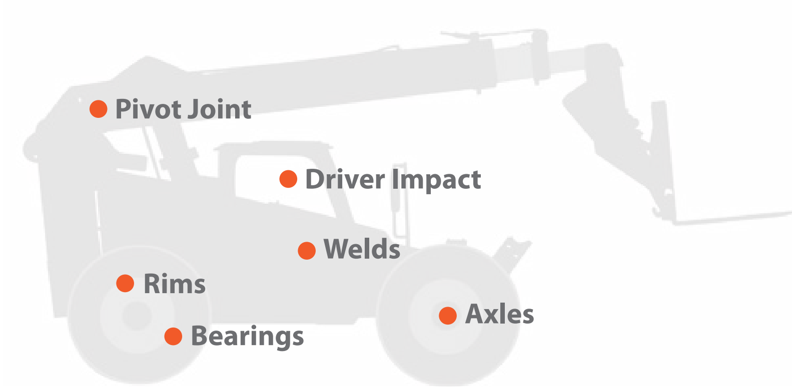
Thus, polyurethane-filled pneumatic tires provide the operator many options to modify the tire's deflection capabilities, either decreased for a more comfortable ride where desired or increased where greater stability is required. Solid tires, in contrast, offer a very limited choice in deflection.

Polyurethane-filled pneumatic tires have a smoother ride as a result of a substantially lower G-force transmission. Higher G-force transmissions can cause operator injury and premature wear and tear on equipment components. The reduced jarring—made possible with polyurethane tire fill—decreases the wear, tear, and deterioration on expensive operational equipment and also eases strain on its components.



Polyurethane-filled pneumatic tires – 41% less G-force transmission to cab/operator than solid aperture tires. Data was collected on a front end loader tested on a track replicating real jobsite conditions.

Tire fill eliminates added maintenance downtime that equates to far more overhead than the cost of a new tire. While solid tires are known for being stable, puncture free, and reliable in the field, there is nothing about solid or aperture tire technology that can prevent the hard, rugged impact of what is referred to in the construction and OTR industries as "Solid Shock".



Solid Shock transfers unnecessary excessive G-force on equipment causing costly and premature wear and tear.

Another stability factor to be considered is the density of a tire. Filling a pneumatic tire with polyurethane adds weight and stability to equipment. Lowering the CoG will provide increased vehicle stability, lessen the risk of roll over in extreme situations, and in most cases, increase lateral grip. Rubber, on the other hand, is denser than polyurethane, resulting in even more added weight. A customer must consider that extra weight may be tougher on equipment. The added stability from additional weight may put stress on hubs and wheel bearings, so additional maintenance may be required. Also, it is important to note that solid tires can exceed ROPS (Roll Over Protective Structures) weight capacity limits on some equipment, creating a substantial safety concern.

5. Driver Safety

"Vibration transmitted to a vehicle is of great concern. Exposure to constant and severe vibrations will ultimately cause premature fatigue and damage the vehicle components. As vehicles are operated by a riding driver, the effects of vibration on the human component cannot be ignored."

– Helmut Paschold, PhD., CSP, CIH
Assistant Professor, Department of Safety Sciences, Indiana University of Pennsylvania, Whole Body Vibration, Field Testing Project Consultant

One major area of differentiation between polyurethane fill and solid aperture tires is in the ruggedness of the ride for OTR equipment operators.

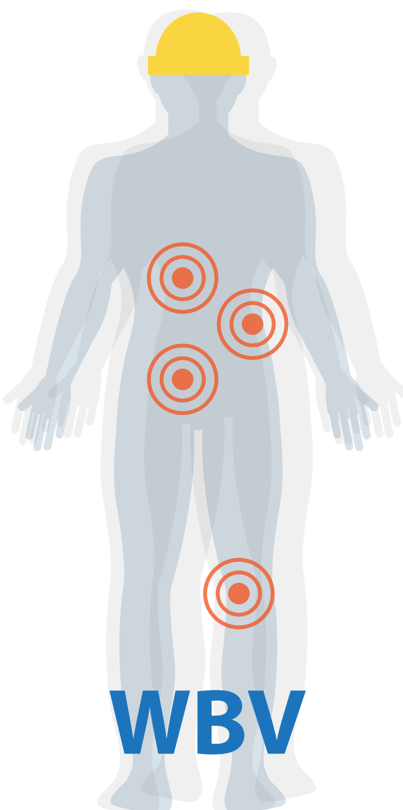
Because tire fill can absorb G-force vibration more effectively than solid apertures, tires filled with polyurethane deliver a smoother, flatproofed ride that is safer and more comfortable for equipment operators, helping to prevent potential injuries that can stall productivity and leave businesses vulnerable to on-the-job worker's compensation claims.

Heavy duty equipment operators seek as smooth a ride as possible. These operators often prefer polyurethane-filled tires, as the comfort and handling characteristics of polyurethane-filled tires are more comparable to those of air-filled tires. Because tire fill is available in a variety of durometers, it provides each piece of equipment with the operating characteristics appropriate for each application. In addition to providing better traction and overall stability, tire fill aids in allowing heavy equipment operators to experience less body jarring effects.

Daily exposure to Solid Shock can cause the operator to experience:

- *Headaches*
- *Lower back pain*
- *Joint pain*
- *Fatigue*

The physical impact of a jarring ride in a OTR heavy equipment vehicle is a phenomenon known in the occupational field as Whole Body Vibration (WBV). This is a medical condition suspected to cause adverse health effects, such as fatigue, lower back pain, vision problems, interference with or irritation to the lungs, abdomen or bladder, and issues with the digestive and urinary systems. Other issues include back injuries (resulting from constant impact on the equipment operator for up to 8 hours per day), which can be a significant symptomatic effect of the WBV phenomenon—and one that may contribute to lessened on-the-job productivity and worker focus.



WBV can also be a major source of lost time in occupational environments, especially for operators of commercial, industrial and heavy equipment/OTR vehicles. About 8 million U.S. workers have occupational vibration exposure. Of these, an estimated 6.8 million are exposed to WBV. Mandatory standards for the regulation and monitoring of worker exposure to WBV exist in Europe, while in the U.S., there are reference standards but no specific regulations.

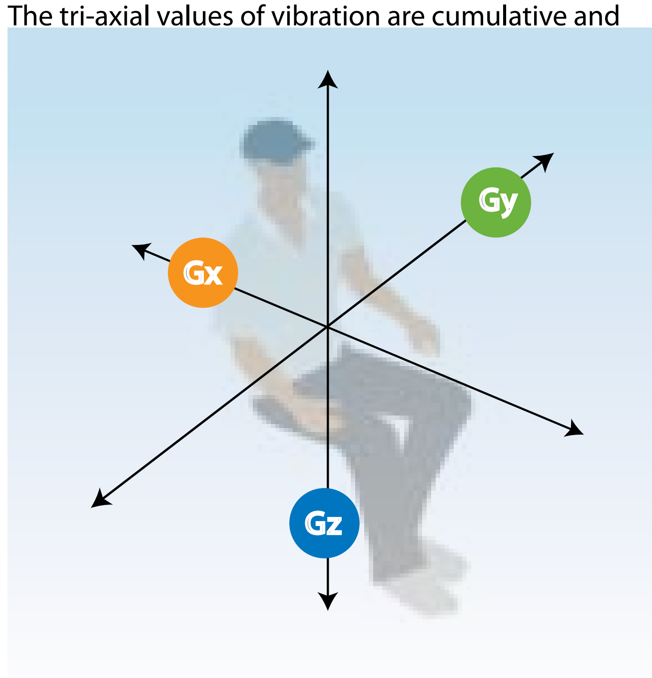
Tire fill, when used in conjunction with the proper tire application, versus solid apertures, may help to significantly reduce the effects of WBV impact. The smoother ride offered by polyurethane-filled tires is a result of the increased deflection that tire-filled pneumatics provide that enables it to decrease G-force impact.

Lower back pain and WBV are often a result of excessive G-force transmissions from solid aperture tires, known in the industry as "Solid Shock."

Polyurethane-filled pneumatics can allow 30% to 46% less adverse G-force effects compared to solid aperture tires, resulting in less equipment and operator fatigue. This graphic helps depict the three axis that make up Whole Body Vibration (WBV) that are directed to a vehicle operator:

- **Gy** – side-to-side motions
- **Gx** – back and forth motions
- **Gz** – up and down movements

The tri-axial values of vibration are cumulative and will be amplified to the driver. WBV is now being explored using these measurements to provide meaning to driver fatigue, discomfort, and injury. All three are happening simultaneously and can be observed in the driver.



The polyurethane in filled tires can be reclaimed

Putting It to the Test: 2016 Field Studies

The first test, conducted on May 2016, teamed up Carlisle TyrFil with the Transportation Research Center (TRC) in East Liberty, Ohio—a leading, independent industrial equipment field testing consultant—to put the comparison between tire filled pneumatics and solid aperture tires to the test.

This test featured a Wheel Loader using 26.5X25 New Firestone L5 Slick with TyrFil @ 55 psi and 26.5X25 New Revolution Solid Aperture tires. Accelerometers were placed on each axle, measuring acceleration in the x, y, and z axis. One triaxial accelerometer was placed in the cab at the base of the seat. Acceleration measurements were recorded at 100 Hz. A total of ten sensors were placed in the vehicle. Runs were conducted over three courses at 5 mph and 8 mph.

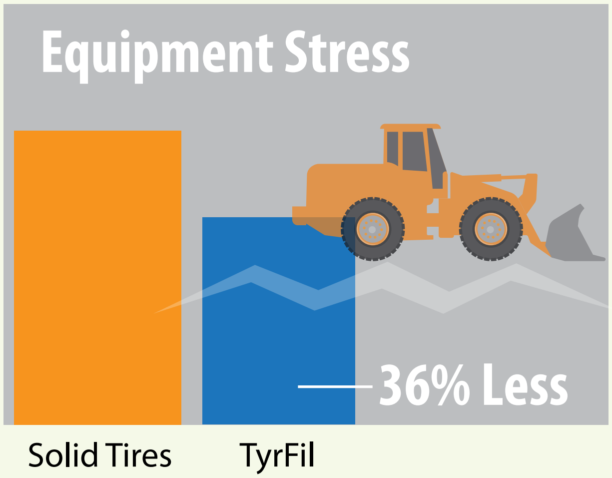
A second independent study, conducted in July 2016, measured and recorded total vibration and WBV levels on a Telehandler at a constructed test track facility in Georgia. The study examined differences in vibration levels between the use of solid aperture tires and Armstrong tires filled with TyrFil on a single piece of equipment on the track designed to approximate conditions that might be found at an industrial or construction site.

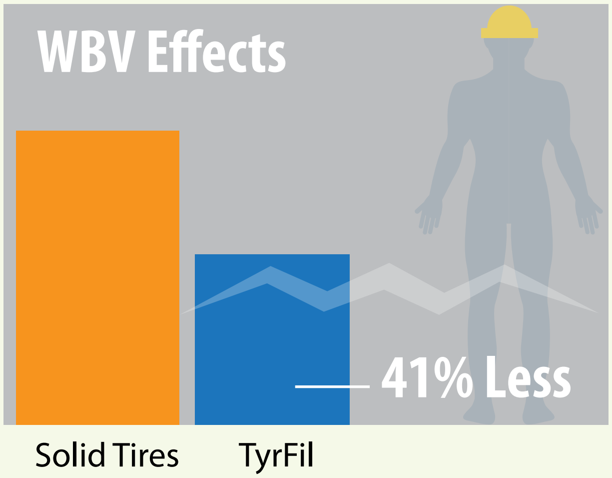
The Results

The test results from both field studies were conclusive. In the May 2016 study, test results proved that pneumatic tires processed with TyrFil outperform solid aperture tires in creating less G-force, which results in less equipment stress (36%) and less adverse effects (41%) to operators.

Specifically, the TRC results demonstrated measurably lower vibration levels in the cabin (floor-mounted accelerometer at the seat mounting) for polyurethane filled tires versus the solid tires on the Durability and Cobblestone tracks. The below charts outlines key findings.

The results were very positive for the vibration reduction on the durability course, in particular, which possessed features that introduced quite severe shocks to the vehicle.





Results are from tests conducted with Carlisle TyrFil™ at the Transportation Research Center (TRC)

Dr. Helmut Paschold, PhD., CSP, CIH Assistant Professor, Department of Safety Sciences, Indiana University of Pennsylvania, added analysis regarding the findings presented by TRC and concurred that the measured cabin Gavg and Gmax values clearly support a claim of reduced vehicle cabin vibration with the use of TyrFil Flatproofing product in pneumatic tires compared to solid aperture tires.

In the second independent Telehandler test, conducted in July 2016, indications corroborated the May 2016 Wheel Loader findings. The Armstrong tires clearly presented the lowest WBV values, both r.m.s. and VDV, loaded and unloaded, among the tires both on the cabin floor and seat/operator interface. According to Dr. Paschold, "The WBV differences are not random, but are significant. The data obtained on the cabin floor should be of greatest interest as it discounts the effects of the vehicle seat.

"Careful selection of an effective properly adjusted vibration-attenuating seat coupled with the use of polyurethane fill in select tires can greatly reduce WBV exposure levels and associated human health risk."

Conclusion

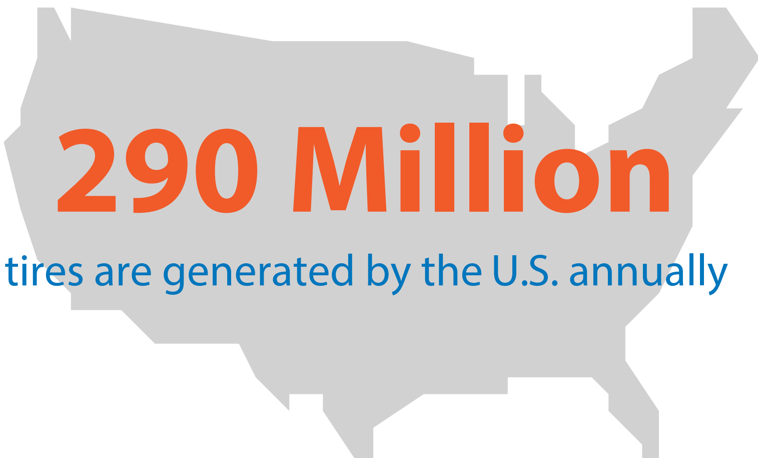
The findings illuminate the reality of solid aperture tires' vibration impact on both operators and their equipment, in comparison to polyurethane filled tires, which offer better shock absorption and a more comfortable, safer ride. While any industry can be slow to adopt new standards, tire fill is a technology whose time has clearly come. The data and field-testing results are defensible and clear: OTR operators who want to protect their people, profits and equipment investment have a flatproofing alternative that simply makes better sense.

6. Sustainability, Recycling, and Retreading

much easier than the rubber in solid tires, creating a second product lifecycle that extends end-user investment and reduces resource consumption. When the tread is worn on a polyurethane-filled tire, but the tire casing is still functional, the tire can be retreaded.

Tests on Carlisle TyrFil's flatproofing product with retreaders demonstrated that there is no degradation in the polyurethane fill even after up to four retread cycles. If the tire is damaged beyond repair, a TyrFil dealer can recover the polyurethane fill and effectively recycle it.
This process saves both operator costs and resources, making it a qualitative and quantitative win for the industry.

An estimated one billion tires reach the end of their useful life each year. Annually, the U.S. alone generates more than 290 million tires.[5]
Tire manufacturers, distributors, and the retail



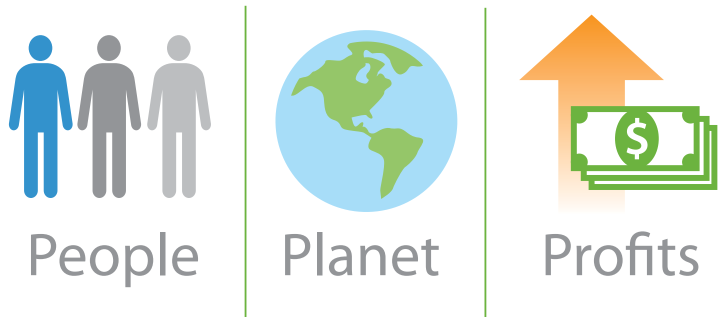
channel are continually searching for answers to identify an environmentally sound way of disposing of scrap tire pieces and creating a sustainable use of natural resources in tire production.

Tires are widely considered to be one of the most toxic and problematic sources of waste, primarily due to the alarming levels of fossil fuels and other raw materials used in tire production. Regrettably, solid tires pose a particularly stubborn obstacle on the path to create a more eco-friendly industry solution.

For one, they take up extensive space to store when discarded—and in a landfill environment, whole tires can float to the top of the landfill, breaking through closures and landfill caps, to create leaking and costly repairs. Secondly, the need for additional landfill square footage to accommodate tire waste can promote mosquito infestation, which in turn breeds vector-borne disease. Lastly, solid tire waste is flammable and at risk of "tire fire" danger, which can take days, weeks, months or even years to extinguish.

Polyurethane tire fill, by contrast, offers many sustainable advantages over solid or aperture tires. For sustainable-minded businesses looking to culture a Triple Bottom Line ethos (nurturing People, Planet, and Profits) when it comes to their equipment operations, investment in a tire fill flatproofing solution greatly reduces their carbon footprint and eliminates whole tire and tire scrap waste from clogging our already over-cluttered global landfills.

In general, polyurethane fill technology is



better for the environment and reduces toxic emissions on various levels. Unlike solid tires, tire fill material is recyclable. The fact that poly-urethane-fill products can be repurposed is a significant measurement of eco-compatibility. Again, because a filled tire can be retreaded for longer life and usability—and because it can be reclaimed much easier than the rubber in solid tires—it saves both the dealer and the customer tangible expenses that can directly impact bottom-line savings.

7. Performance Comparison By Application

While different flat free tire solutions have obvious advantages and disadvantages based on their construction and composition, they are only of importance if users value them. In a survey of operators conducted in June of 2014, those inherent benefits are reflected in actual customer preferences.

Performance By Application, Based On Customer Survey[6]

	Mining	Agriculture	Construction	Forestry	Material Handling	Scrap Metal	Ground Support
Solid Tires							
Cushioning, Flotation & Shock Resistance	Average	Worst In Class	Average	Worst In Class	Average	Worst In Class	Average
Stability	Average	Average	Average	Worst In Class	Best in Class	Worst In Class	Best in Class
Tear, Abrasion & Durability	Average	Best in Class	Average		Best in Class	Average	Best in Class
Traction	Average	Average	Best in Class	Worst In Class	Best in Class	Best in Class	Best in Class
Polyurethane-Filled Pneumatic Tires							
Cushioning, Flotation & Shock Resistance	Best in Class	Best in Class	Best in Class	Best in Class	Best in Class	Best in Class	Best in Class
Stability	Best in Class	Best in Class	Best in Class	Best in Class	Best in Class	Best in Class	Best in Class
Tear, Abrasion & Durability	Average	Best in Class	Average	Best in Class	Best in Class	Average	Best in Class
Traction	Best in Class	Average	Best in Class	Best in Class	Best in Class	Best in Class	Best in Class

= Best in Class = Average = Worst In Class

8. Cost

Tires are one of the most expensive maintenance and repair costs on an industrial vehicle. From a pricing standpoint, it is difficult to precisely compare the two types of tires, as there are many variables to be considered. The initial price paid for tires is generally higher for solids than for polyurethane-filled tires.

As one indication, a large mining customer located in South Africa tested both solid and polyurethane-filled pneumatic tires and found that using heavy-ply, deep tread (L5 or L6) pneumatic tires filled with polyurethane in these applications provides a better value.[6]

Solid aperture tires can come with hidden costs. Excessive G-force transmission, which is considerably greater in solid tires, and the resulting "Solid Shock" can produce premature damage to the equipment and injury to the operator.
Solid Shock can generate expensive damage to the axle, hubs, engine mounts, and transfer cases, just to name a few. To the operator, Solid Shock can create headaches, lower back pain, joint pain, and fatigue. Prolonged exposure to Solid Shock can induce Whole Body Vibration, a measurable muscular-skeletal and neurological injury which results in spinal, nerve, and internal organ damage. These real occupational hazards can cost hundreds of thousands of dollars.

Summary

OEMs, aftermarket tire dealers, and global OTR tire distributors all have a serious decision to make when it comes to tire selection. Presumably, most operators will seek the most comfortable ride and superior product performance. Purchasers likely also know that tire fill offerings are among the spectrum of available options, but until recent years, they may not have truly recognized the flatproofing advantages that tire fill offers the industry. While solid tires offer a stable option that can be long lasting and reliable, they also incur non-direct operator costs. These include greater wear and tear on the vehicle, the potential negative effects of Whole Body Vibration on equipment operators, and fewer eco-benefits to protect the environment.

Tire fill offers a cost-effective, pro-environment tire flatproofing solution for improved safety and productivity that delivers the reliability required for rigorous OTR applications. Additionally, the use of polyurethane-filled tires reduces vehicle damage and deterioration and may prevent worker injury and liability claims.

When performance, cost considerations, and worker safety are paramount, especially in hazardous environments, tire fill delivers on a myriad of levels. For one, a filled tire will never go flat—it allows equipment to operate over broken glass, nails, sharp metals, rocks, rebar, and other damaging objects. The durability of polyurethane fill has been proven to perform in this capacity time and time again—in literally thousands of demanding applications for the construction, waste management, mining, municipality, military, and rental equipment markets. Despite cuts and punctures, filled tires will keep performing, increasing productivity and eliminating costly downtime for field operators.

A cost-effective solution for OEMs, aftermarket tire dealers, and global distributors, the use of polyurethane fill guarantees that tires will remain "flat free" —defraying frequent vehicle repair expenses for industrial, and heavy equipment operators. The ability to effectively recycle tire fill using appropriate equipment, and methods also helps to drastically ease environmental strain by helping to keep used fill material out of domestic and international landfills, contributing to a healthier, safer planet. Filled tires can be retreaded, in many cases multiple times, extending the life of costly tire casings.

Carlisle TyrFil stands alone in the industry as the one global tire fill provider that seamlessly integrates the highest product integrity with an international customer service and supply network that is second to none.

Please visit www.carlisletyrfil.com for additional information, including an instant Profit Analysis Calculator to see the total cost savings of using TyrFil Flatproofing for your business.

	Solid Tires	Polyurethane Filled Tires
1 Adaptability and choice	−	+
2 Wear, tear and durability	=	=
3 Traction	−	+
4 Cushioning, stability, and shock resistance	−	+
5 Operator safety and comfort	−	+
6 Sustainability, recycling, and retreading	−	+
7 Performance comparison by application	−	+
8 Cost	=	=

References

1. John Dunlop, Charles Goodyear, and the History of Tires. https://www.thoughtco.com/john-dunlop-charles-goodyear-tires-1991641

2. Solid Rubber to Steel Bands: A Brief History of Tires. https://thenewswheel.com/solid-rubber-to-steel-bands-a-brief-history-of-tires/

3. Polyurethanes, History. http://www.polyurethanes.org/index.php?page=history

4. http://dictionary.reference.com/browse/traction?s-t

5. World Business Council for Sustainable Development

6. Corrie DeVilliers, with Cool Ideas, prefers using a heavy-ply pneumatic tire with foam fill in loaders at Power Metal Recyclers (PTY) LTD in their metal recycling facility near Johannesburg, South Africa.

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