Twaron drives tires
Driving improvements in tires

Twaron
The power of Aramid
1 The development of using Twaron in tires

Twaron is a very strong, light-weight para-aramid fiber produced by Teijin Aramid. It has a high modulus, is thermally stable and has high chemical resistance. Since the development of Twaron in the 1970s, Teijin Aramid has produced the monomers, polymer and yarn in the Netherlands. Twaron is used in a great range of applications, such as tires, optical fiber cables, composites, ballistic products and many more. Twaron is widely recognized by many industries as a quality product with great performance and high durability.

Unique qualities of Twaron
Twaron has a unique combination of properties:
• high strength (weight-for-weight, Twaron is three to five times stronger than steel)
• high modulus
• low elongation
• high-temperature resistance
• high chemical resistance
• no corrosion
• no creep

Chemical structure of Twaron
Twaron para-aramid is formed through the reaction between an amine group and a carboxylic acid halide group. The chemical structure of Twaron and its monomers is depicted below:

H₂N \[\text{p-phenylene diamine}\] \[\text{C} \quad \text{C} \quad \text{Cl} \quad \text{Cl}\] \[\text{terephthaloyl dichloride}\]

\[\text{N} \quad \text{N} \quad \text{C} \quad \text{C} \quad \text{O} \quad \text{O} \quad \text{structure of Twaron}\]

\[\text{H} \quad \text{H}\]

\[\text{polyparaphenylene terephthalamide (aramid)}\]
Comparison of different reinforcing materials based on mass

![Comparison of different reinforcing materials based on mass](image)

*Figure 2: Tensile properties of Twaron in comparison with other materials*

2 Twaron in tires

**Optimum performance**

The superior performance-to-weight ratio of aramid fiber makes it the first-choice material for reinforcing or protecting high-performance tires.

Maximum performance at a minimum weight has become a key requirement for many types of tires, and not just the highest categories racing and ultra-high-performance (UHP) passenger car tires. As a result, more and more companies are focusing on reducing the weight of their car tires for the general public. Choosing Twaron tire cords and fabrics will not only significantly reduce the tire weight, but can also give additional benefits with regard to handling performance and reduced fuel consumption, while maintaining general requirements such as safety and longevity.
Function of Twaron in tires
Twaron is used for two main purposes: as reinforcement and as a protective material.

Reinforcement
Twaron outperforms other commonly used tire reinforcement materials – rayon, polyester, polyamide and steel – on strength and modulus when compared by weight. Besides, compared to polyester and polyamide, it has much better dimensional stability characteristics due to the high crystalline structure of the polymeric molecules. This gives a significant improvement in the flat spotting behavior, which is a typical unwanted phenomenon, for example in UHP tires with a polyamide cap ply. The crystallinity also ensures the same performance over the lifetime due to less dimensional change, when compared to polyester and polyamide. These are the major values that drive the increasing use of aramid in high-performance passenger car tires.

An important aspect in tires is the resistance to fatigue, which is extremely critical in dynamic applications such as the side wall of a tire. The carcass cords in this area must survive the stresses during the tire’s lifetime and under all conditions, even at extreme high speeds. Therefore, manufacturers pay a lot of attention to the endurance of a tire cord during the tire development process. Twaron cords in this part of the tire are designed with a high twist level, which is an effective method to improve the fatigue performance. It ensures safe performance from the moment of purchase until the tire is scrapped. Such high twisted cord constructions have proven to be the right solution for aramid in the carcass, no matter how tough the driver puts his car to the limit.

New laws on CO2 emission reduction of cars are pushing tire producers to look for alternatives to steel belts to reduce the weight of the tire. At present, Twaron containing cap plies are essential for UHP tires to keep the steel belt in a precise round shape at very high speeds. In the future, the use of steel as belt reinforcement material is expected to be partly substituted by other lighter solutions. Aramid is a good candidate to take this position as tension member in the belt.
Protective

Aramid is widely used in ballistic and protective apparel applications to provide protection against penetration of bullets or cuts from sharp objects. It has also found its way into the tire market to provide protection against punctures and cuts. Many companies have an interest in this because better protected tires improve safety, lifetime, comfort and increase productivity. The following are a few examples of where aramid is currently used in a protective application:

• After the Concorde accident in Paris, July 2000, which was caused by an exploding tire of which fragments hit the fuel tank, the aircraft industry increased their safety requirements and are demanding tires with better puncture protection. These so called FOD (Foreign Object Damage) protected tires often have an additional breaker layer under the tread in which Twaron can be used.

• One of the biggest frustrations of a cyclist is a flat tire. There are several solutions to improve the puncture protection. In thin racing tires for example, a fine and dense Twaron fabric can be placed under the tread. In city or trekking tires the protection can be improved by adding Twaron short fibers to the tread compound. Both give the same benefit to the cyclist, namely to give no chance to thorns or glass particles to puncture the tire.

• Mining industry is suffering reduced productivity due to stranded vehicles with damaged tires. In severe conditions some tires only last a month and are then so heavily damaged that repairs are no longer possible and the tire needs to be scrapped. Sharp rocks and stones have penetrated into the tread and damaged the steel belts. A Twaron breaker layer can significantly improve the tread puncture protection. A second solution could be to add Twaron short fibers to the compound.

• In underground mines where there’s little space to maneuver the vehicles often scrape along the walls. Tires are suffering sidewall damage. Twaron fabric can be a solution to protect the sidewall and to improve the tire lifetime and increase productivity.

• Farmers are facing a challenge with their agriculture tires that need to be resistant to punctures when working in the field. Some of the crop has been genetically modified to increase the yield and their stalks are so tough that they easily penetrate the tires. An aramid breaker layer improves the puncture resistance and reduces downtime of the equipment.

These examples make clear that there is a broad demand for protective solutions. Aramid yarns and fabrics have found their way into many different designs and various types of tires where they fulfill the specific needs for the usually high demanding application.

Twaron

The power of Aramid
Trend to lower tire weight
Following the global trends to reduce CO2 emissions, there are many countries and regions in the world that have implemented laws to enforce the reduction of CO2 coming from cars. In Europe, for example, the 2015 limit is 130 g/km and this will be further reduced to maximum 95 g/km in 2020. Not complying to this law is not an option due to the high penalties that otherwise need to be paid by the car manufacturer. They are therefore increasing their requirements and demand their suppliers to reduce the weight of the components. Tires are a great area of improvement in cars, since they are part of the “unsprung mass” – that is, the mass of the suspension and all components directly connected to it. A car with a lower unsprung mass maintains better contact with the road during the rapid vertical movements when driving over irregular road surfaces. Lower tire weight also contributes to better traction and steering control during hard braking or accelerating by reducing the tendency for wheel hop.

Lower tire weight reduces the moment of inertia of the rotating wheel. This not only allows for faster acceleration of the vehicle, because less energy is needed to get the wheels rotating, but it also causes a lower gyroscopic effect. This “gyro effect” causes a torque on the steering wheel during a change in the direction of the axis of rotation of the wheel. The torque is proportional to the moment of inertia, the rotational speed and to the rate of change of the steering angle. This gyro effect is particularly relevant to racing tires. Fast accelerating, braking and cornering will exert large forces on the rims and brakes. By lowering the tire weight, racing cars can accelerate and brake faster and possess a better cornering performance. Many racing tires contain aramid components.

It is not only the weight that leads to above mentioned benefits, but also the use of less rubber. Due to its higher strength, aramid can often reduce the number of reinforcement layers which means less rubber is used. Rubber heats up during dynamic stresses, called hysteresis. This energy is delivered by the movement of the car, so comes from the fuel. More rubber simply consumes more energy than less rubber. Reducing the rubber thickness by using light-weight aramid solutions is an effective method to reduce the energy consumption and CO2 emissions.
Overview of Twaron’s advantages in tires

• Higher performance
  – better strength – specific weight ratio than steel, rayon and polyester
  – better dimensional uniformity than polyester and polyamide
• Increased safety
  – better road contact at high speeds due to better control of the tire shape
• Higher comfort
  – better flat spotting properties than polyamide
  – more flexible sidewall due to thinner material compared to polyester/polyamide
• Less fuel consumption (= CO2 reduction) due to lower rubber thickness
• Improved protection
3 Twaron in different types of tires

The stress-strain diagram of Twaron yarn shows a rather straight curve (see figure 2), however, when converted into a tire cord the possible shapes of the tensile curve are almost endless. This makes Twaron suitable for several applications in many different types of tires. Below are the main tire types and applications described.

Figure 3: Overview of different parts in a tire, which can feature Twaron yarn

3.1 Passenger car tires

While Twaron was initially only meant to be used in the ultimate category racing tires, Twaron’s properties have been widely used in UHP tires (rated > 240km/h) for more than a decade, and this fiber has more recently found its way down into high-performance (HP) tires. The UHP tires with the highest speed ratings require ultimate performance properties at the lowest possible weight, which is exactly what Twaron provides.

Twaron yarns have very good short- and long-term dimensional stability properties, which give the tire uniformity of shape and properties under varying temperature conditions and at variable speeds. This is maintained during the entire lifetime of the tire. On a laboratory scale, this behavior is shown as high modulus, low shrinkage and absence of long-term
creep properties. As illustrated in figure 3, the unique set of properties have introduced Twaron in different parts of the tire. Many developments with Twaron are ongoing in the tire industry, giving the future a bright outlook.

Figure 4: Michelin Pilot Super Sport promotion material, 2010 (courtesy of Michelin)

**Cap ply**
The majority of the current para-aramid volume in the tire market is for the cap ply. This is a reinforcing layer on top of the belt layers that keeps the shape of the tire better at high speeds and maintains good contact with the road. This is essential in high speed tires when they are pushed to their limit. Before aramid was developed, the cap ply was usually made of two layers nylon. This technology is still used by many tire companies. The disadvantage of nylon is the loss of modulus at higher temperatures, which can reduce the driving performance. Besides, nylon is sensitive to flat spotting that is particularly an undesired behavior by luxury car brands. Tire manufacturers that are in OE supply business therefore often choose aramid solutions to improve the flat spot behavior and to better meet the needs of the car manufacturers. Due to increased consumer awareness, the industry is now also starting to produce high-speed tires with aramid technology for the aftermarket. This shows that aramid is indeed an excellent choice for cap ply reinforcement yarn.

**Sidewall**
Para-aramid can be used to stiffen the bead area or side wall of UHP tires. Braking and accelerating forces are more easily directed from the road to the rim and vice-versa if the bead area and sidewall have enough stiffness. Twaron is most commonly applied as full aramid cord fabric, but also in the shape of short fibers or pulp. The short fibers are commonly dipped chopped fibers (DCF). Typical length grades of short fibers vary between 1 to 3 mm.
Run flat tires (sidewall reinforcement)
A run flat tire needs to have enough stiffness in the sidewalls to carry the load of the car when the tire has lost air pressure. Conventional reinforcing materials stiffen sidewalls with multiple layers of reinforcing material and rubber. This results in heavy tires that are difficult to handle because they add significant weight to the car’s unsprung mass. The use of aramid cord allows the use of less rubber in the sidewall. This improves the comfort and driving performance. An additional benefit is better thermal conductivity due to less rubber, which reduces the chance of heat-related rubber damage. Aramid is used in many types of run flat tires that come to the market nowadays.

Carcass
To further reduce the weight of the tire, industry experts are looking into aramid technology to replace (parts of) the polyester and rayon carcass layers. Because of its high strength, aramid can replace two layers by only one, saving weight and fuel consumption due to the use of less rubber and reinforcement material. Aramid needs to survive the high dynamic compression stresses in the sidewall, which is easily possible with the use of special developed twisted cord constructions. Some renowned tire manufacturers are already commercial with aramid carcass technology, which indicates it is technically safe and commercially achievable.

Belt
Substituting heavy steel layers with light-weight aramid gives another opportunity to significantly reduce the weight of the tire. Aramid is suitable to be applied in the belt layers. Although there is interest amongst tire manufacturers, it is expected that a breakthrough will come after implementation of aramid technology in the carcass.
3.2 Racing car tires

A racing car tire is similar to a passenger car tire except that it operates under the highest demanding conditions: extreme speeds, acceleration, braking and cornering and constant speed changes require the best of reinforcement technology that is available. No wonder that the top of the industry often chooses Twaron.

Racing tires need to have low unsprung mass to improve the road contact and handling performance (see more details in Section 2). Twaron is a very suitable reinforcement material and can be used in the cap ply, belt and carcass. Due to the extreme forces many racing tires are built with additional aramid sidewall fabric reinforcement to improve the direct transfer of forces between road and rim. The use of so much aramid in a racing tire makes it very stiff. This can reduce the comfort, but for racing cars this is not a primary design parameter. Performance comes first!

Temperatures typically get higher than in passenger car tires due to the more extreme conditions. This is another aspect that supports the use of aramid. Because of its crystalline polymeric structure, Twaron is very resistant to high temperatures, and it does not show degradation of properties over time and is very dimensionally stable.

In the same way that some technologies that are nowadays considered common in the market originate from the aerospace industry, tire manufacturers are using a similar approach and they use their experience obtained from racing tires to design or improve their passenger car tires. From designing a racing car tire, one can learn a lot about the future design of tires in general.
3.3 Truck and bus tires

In truck and bus tires, steel cords are commonly used as a reinforcement material in the belt, carcass and bead. Twaron yarn can be used to replace steel. The advantages of Twaron above steel cord are:

- **Lower weight**
  - less fuel at equal payload, means less CO2 emission, or
  - higher payload at equal fuel consumption
- **Improved resistance against sudden indentation**
- **Resistance to corrosion**

Even though aramid is very suitable as a reinforcement material, it is not yet widely used in truck and bus tires. Legislation on lowering the CO2 emissions of passenger cars has given a strong push to the use of aramid. The same can be expected when similar legislation for trucks is developed.

3.4 Aircraft tires

The low weight of aircraft tires is important to reduce the total weight of the plane and to save fuel. Aircraft tires need to be safe under the most demanding circumstances: withstanding take-off and landing speeds up to 300 km/h, as well as carrying the heavy aircraft. No wonder that aramid is preferred as a reinforcement material, as it ensures optimum performance at the lowest possible weight. As previously explained, aramid protective solutions are increasingly used in these types of tires.

3.5 Bicycle tires

These tires have much different dimensions and stress levels than large aircraft tires, however, aramid is still be successfully used. The breakthrough came when aramid was used in the bead of foldable tires. It had always been inconvenient to take a spare tire on a cycling trip due to rigid round shape, but the introduction of foldable tires with aramid bead changed this, and spare tires were suddenly no larger than a small hand-sized package. Aramid is substituting steel in the beads to make the tire light weight and foldable, which is appreciated by professional and recreational sports people.
Another successful application is the use of aramid fabric as protective layer in the tread. Using a dense and thin fabric can be very effective against the penetration of thorns or small glass particles. This anti-puncture solution can be typically found in high performance racing or MTB tires. Serving the same purpose but using a different technology is the addition of aramid short fibers to the tread compound. The fibers increase the compound’s hardness and low strain modulus, making it tougher for particles to penetrate. This is more suitable for tires with a thicker tread, such as trekking or city tires. Perhaps it is not known to many cycling enthusiasts, but aramid solutions prevent many punctures on- or off-road and contribute to more fun during bike rides.

3.6 Agriculture and OTR tires

These tires are mainly used in off road areas like farm land, mines and forests. There is a vast interest in improving the protection against punctures and cuts, because any downtime of a vehicle reduces productivity of the farm, mine or other type of business. Solutions are often found in the use of aramid as a protective layer or by adding short fibers to the compound to improve cut, chip & chunk behavior. Besides serving a protective function, aramid can also be used to reinforce the belt or carcass. With the right cord construction, aramid can substitute steel, polyester or nylon and reduce the weight of the tire significantly. Due to the use of fewer reinforcement layers, there is less rubber in the tire, which has a positive effect on the heat buildup that is often causing premature tire failure. Aramid protects and increases these tires’ lifetime.
4 Hybrid Technology

As shown in Section 1, aramid yarn has a high modulus and high strength. It shows a much different elongation behavior than other synthetic yarns such as polyester or nylon. This gives it a unique set of properties that is highly valued in high-performance tires. But the high modulus behavior is not desired at all moments. For example, during the vulcanization process where the bladder pushes the green tire into the mold, the tire grows a few percent in dimensions. This puts stress on the reinforcement cords that need to grow or move in the same ratio as the tire does. The more resistance the cords give, the more difficult it is to make a high-quality tire with high reproducibility and without errors. Low modulus yarns give better results in this part of the process. However, after the production process the manufacturer wants to see high modulus behavior to get to the high performance level of the tire. A solution has been found in the use of hybrid cord constructions. Hybrid cords consist of a mix of two different yarns that are typically twisted into a tire cord. By varying parameters such as yarn type, twist level or process settings, an almost endless variation of stress-strain curves can be obtained. Hybrids can be a very effective way to create low modulus behavior during tire vulcanization and high modulus behavior in the vulcanized tire that is ready to be mounted on a car.

Another benefit of hybrid cords is an improvement of fatigue behavior. While full aramid cords can suffer abrasion damage between the aramid plies at the very small filament level, the combination of different yarns in a hybrid cord construction can reduce the damage in the aramid yarn to zero. This makes such constructions ideal in parts of the tires that operate with a lot of dynamic stress.

The benefits of hybrids are:

- **Low modulus behavior during vulcanization**
- **High modulus behavior in the vulcanized tire**
- **Improved fatigue**
- **Large freedom of design, with nearly unlimited number of stress-strain curves possible**
Figure 5: Force-elongation curves of 2-ply and 3-ply hybrid cord constructions and the effect of twist level variations.
5 Aramid Short Fibers

For many years, short fibers have been used to reinforce all sorts of rubbers and thermoplastic elastomer products. The performance of tire compounds can be enhanced by the addition of small amounts of these aramid fibers, often in a way which is impossible with conventional particulate fillers or with other fibers. Sulfron® is the brand name for the chemically activated aramid fiber granules that improve the performance of rubber compounds by reducing the hysteretic properties, which translates into better rolling resistance or fuel economy and improved durability and mileage. When added to rubber compounds, aramid short fibers can improve several properties. These include an increase in the low strain modulus, abrasion, puncture and tear resistance, dynamic fatigue properties, energy loss and green strength. The loading required is typically much lower than for other short fibers minimizing adverse effects, such as wicking and permeation. An additional advantage is that unlike particulate fillers, anisotropy in technical properties is possible due to the orientation of the fibers during processing. This means that the properties in the Machine Direction (MD) are different to the properties in the Cross-Machine Direction (CMD). This should be considered when developing an aramid short fiber reinforced compound using the fiber orientation that is given by the processing technology, and giving attention to the desired compound improvement. Properties may have different optimum behavior depending on the orientation. For example, abrasion resistance is best when the fibers are oriented on-end, whereas an increase of modulus requires fiber orientation in longitudinal direction.
About Teijin Aramid
We are Teijin Aramid, a subsidiary of the Teijin Group with a passion for aramid. Our commitment both to our products and to our customers has made us a global leader in aramids. Wherever strength, safety, heat or flame resistance, low weight or sustainability is required, you will find our Twaron®, Sulfron®, Teijinconex® or Technora®. Our products are used worldwide in many different applications and markets, including automotive, ballistic protection, marine, civil engineering, protective clothing, optical fiber cables, and oil & gas. With our four high performance aramids – produced at our plants in The Netherlands and Japan – we offer the widest range of products. And, with unrivalled expertise and experience we are able to continuously work on further innovations. Often in cooperation with customers and partners through our worldwide sales and marketing organization. That’s the power of aramid. If you would like to learn more about the world of aramid or to exchange ideas on developing new solutions, please go to www.teijinaramid.com.

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