Continental
The Future in Motion

HIGH-TECH PRODUCT

TYRES

From raw material to series production tyres

INTRODUCTION

Before it is ready for series production, a new tyre type must first pass through several sections of our R&D department in a process lasting between three and five years and involving a host of indoor and outdoor tests. This Information Book provides an in-depth insight into how Continental tyres are developed, taking a separate look at each of the different labs where our teams test new tyre prototypes and simulate their performance in different driving situations.

Virtual tyre development has huge potential, especially when it comes to developing tyres for alternative drive systems such as those used by electric vehicles. As well as enabling far more accurate and resource-efficient tyre characteristic testing, it allows new findings to be fed into the ongoing development process much more quickly.

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MIXING LAB

Tyres are a truly high-tech product, each one the result of thousands of hours of work. It all begins in the mixing room, where the entire production process is replicated. But rather than making actual tyres, the mixing lab produces the vulcanized test pieces used in lab tests. These rubber sheets, rings and thin rods are produced to the exact recipes specified by the materials development department, but their shape and geometry is optimized for the relevant testing methods and equipment. The test pieces are sent to R&D departments such as the Compound Testing Lab, Chemical Testing Labs and Special Labs, where the appropriate tests are carried out.

Creating the perfect blend

The basic ingredients that go into a tyre compound include synthetic and natural rubbers, silica, technical carbon black, sulphur, zinc oxide, oils and resins. These ingredients are weighed out – in some cases to a precision of one thousandth of a gram – and blended together to create a compound. Around 1,000 ingredients are available, in different grades and types. The lab also has the capability to make novel recipes and innovative raw materials such as the sustainable dandelion rubber Taraxagum.

Making the test pieces

The uncured compounds are produced in special internal mixers of various sizes, allowing the Mixing Lab to make smaller or larger quantities of compound as required. Standard processes are then employed to roll out the uncured compounds before they are cut to size and vulcanized in curing presses at the specified temperature. Colloquially known as the “baking time”, the duration of the vulcanization process is also critically important. Within the tyre development process, the Mixing Lab is responsible for continuous optimization and quality assurance. This includes testing the quality of raw materials such as resins, oils and carbon black; all raw materials undergo extensive quality testing before they are approved for use in tyre production. The mixing room thus acts as a technical bridge between the materials development team and the various testing departments.

Material testing

Every year, the mixing room prepares several thousand compounds. These are used to produce thousands of test pieces that subsequently undergo a range of different material tests. The main focus of the development process is on the tyre tread. However, test pieces are also produced for the sidewall and casing, where the emphasis is on the bond between rubber and metals or synthetic fibres.

COMPOUND TESTING LAB

Rubber is a truly fascinating material to work with and exhibits viscoelastic behaviour. In its original, unvulcanized state, it can be shaped plastically like modelling clay. Once it has been vulcanized, however, its elastic properties come to the fore, allowing it to stretch and then return to its original shape when the stress is removed. Depending on the composition of the compound, rubber can show either elastic resilient behaviour or energy-absorbing behaviour. Consequently, the rubber compound recipe is key to a tyre's functionality, influencing both braking performance and rolling resistance. A balance must be struck between maximizing braking performance in the interests of safety and minimizing rolling resistance in order to reduce fuel consumption.

The Compound Testing Lab investigates new rubber recipes to determine how well they are able to reconcile these conflicting priorities. A wide range of testing techniques are employed to establish whether the material developers' recipe ideas are on the right track: Do the new materials fulfil the physical criteria that the development department has specified for the tyres?

Testing in the Compound Testing Lab

The tests typically carried out in the Compound Testing Lab include microabrasion tests, strength tests, tear, compression and impact strength tests, and tests to investigate the material's elasticity, dimensional stability and viscoelastic behaviour. Special equipment is used to analyse friction mechanisms on a wide range of different surfaces, providing a deeper insight into the phenomenon of rubber friction. One of these testing machines carries out extremely precise measurements of the friction coefficients of rubber test pieces on different substrates – such as asphalt, concrete, snow and ice – in a test environment that can be set to a wide range of temperatures. Once the rubber test piece has been mounted on the machine, it can be moved over the substrate at high speeds. This allows local slip velocities occurring at the tyre contact patch during braking and traction testing to be simulated in the laboratory. High acceleration values can also be achieved. The test piece can be pressed against the different substrates at high pressures so that the real-world stresses encountered by the full range of tyre types (motorbike, car, bus and truck tyres) can be replicated in the lab. These tests make it possible to predict the outcome of traction-focused tyre tests (e.g. on ice and snow) and rank the effectiveness of different compound variants. The High-Speed Linear Friction Tester (HSLFT) provides the technological basis for the Automated Indoor Braking Analyzer (AIBA) at Continental's Contidrom test facility. The HSLFT enables precise control of surface and temperature conditions, while the AIBA provides the link between controlled test conditions and the real world.

SPECIAL LABS

A material's properties are more than the sum of its ingredients – the tyre's final characteristics are also influenced by the interactions between the compound's components. Despite their minute particle size, fillers such as silica and highly active carbon black are critical to tyre function, combining to produce fractal structures that resemble coral branches. These form a network that strengthens the tyre's mechanical properties. The Continental R&D department's Special Labs provide in-depth insights into these structural and property relationships.

Scanning electron microscope

In the Special Labs, these structures are revealed by a scanning electron microscope (SEM). An electron beam scans the material's microstructure, providing striking insights into the rubber's morphology and elemental composition.

Atomic force and transmission electron microscopes

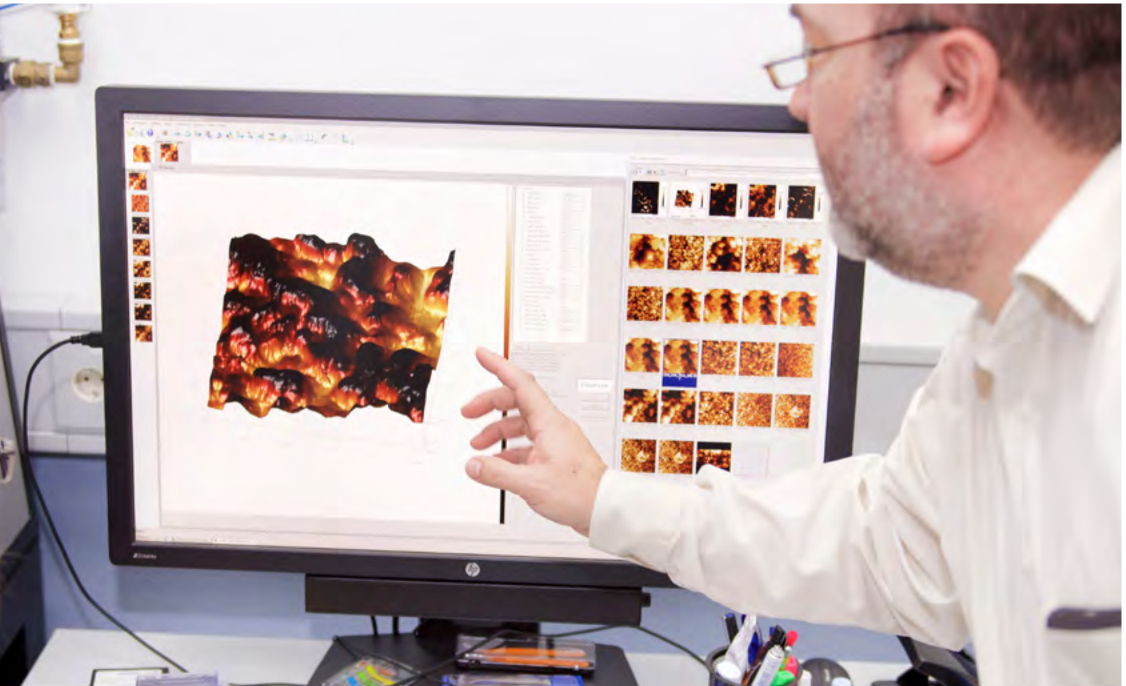
The atomic force microscope (AFM) is a special deep dive analysis instrument that reveals the rubber material's nanostructure. Atomic forces bend a cantilever with a nanoscale silicon needle on the end. The needle tip raster scans the material line by line. Located in its own dedicated lab room, the transmission electron microscope is used to view highly active carbon black, silica and other nanofillers down to a particle size of 0.3 nanometres.

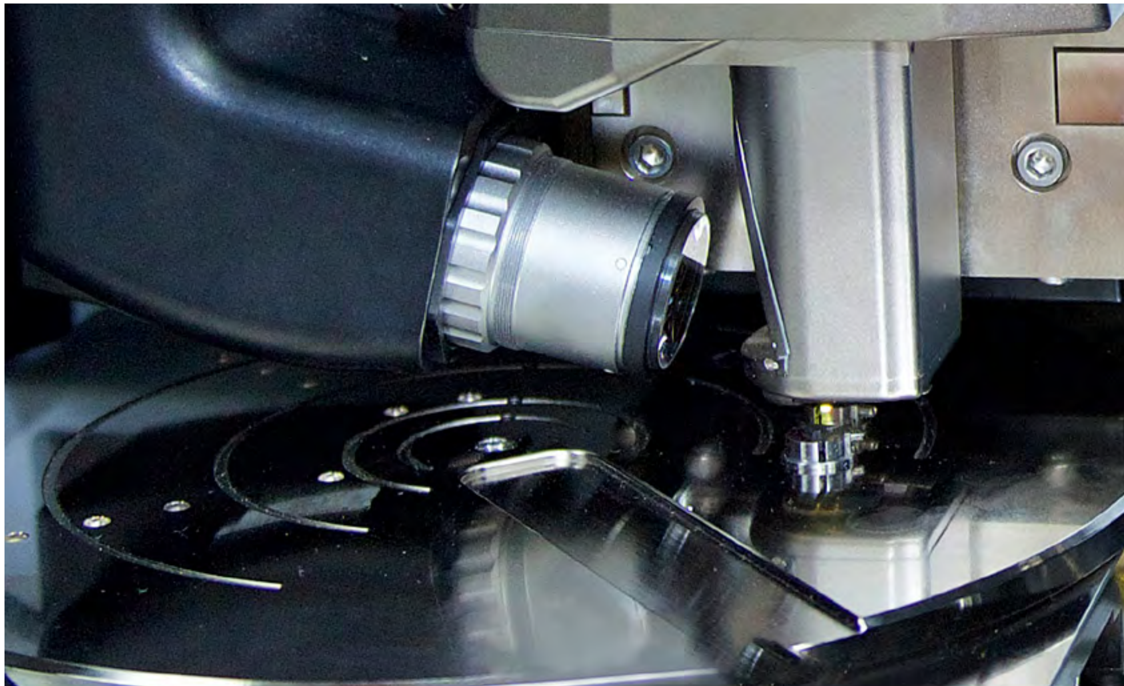
3D digital microscope

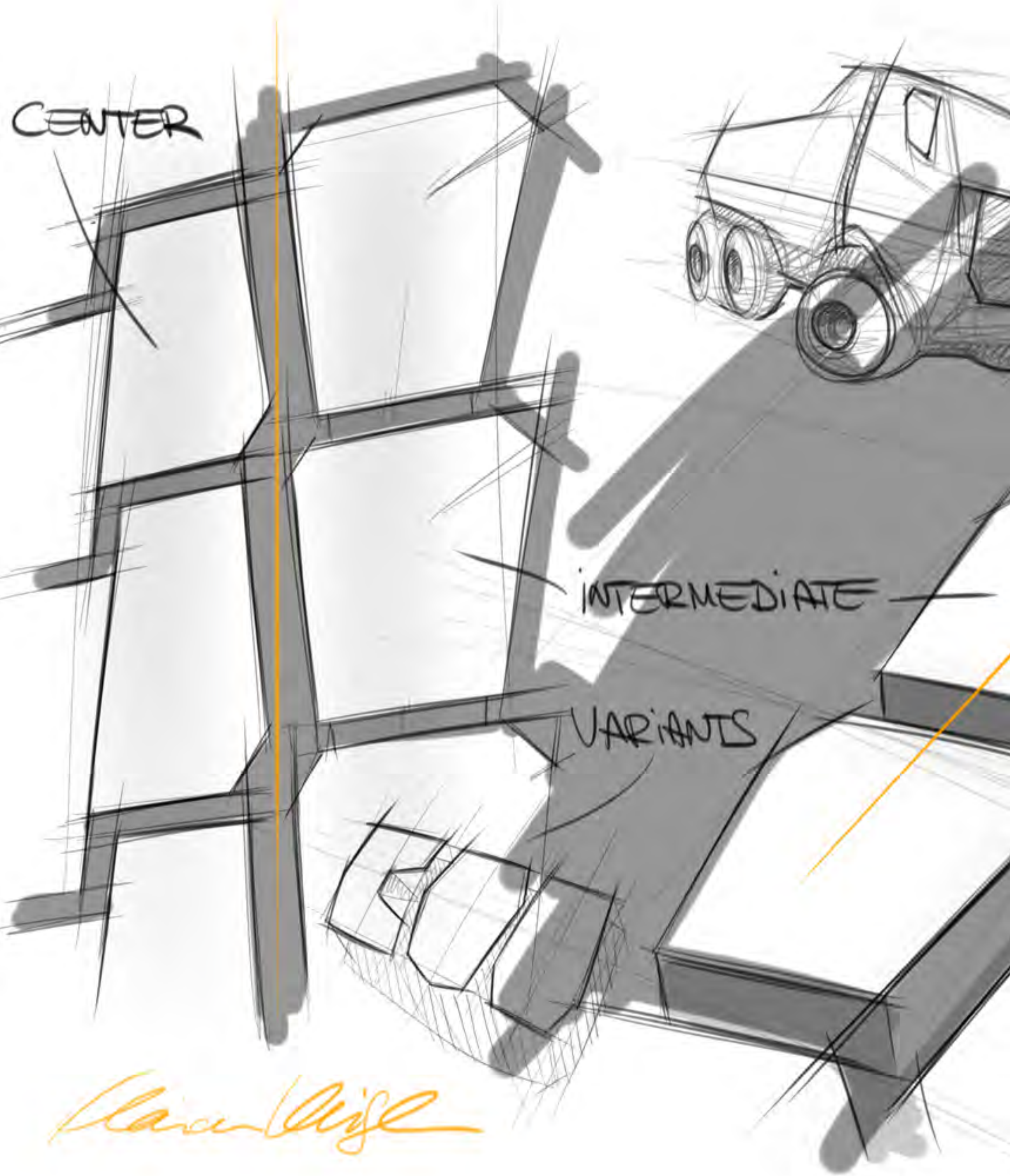
The 3D digital microscope provides further insights into this microscopic world. This optical microscope reveals the topography and surface roughness of rubber at the microscale. Wearing virtual reality headsets, researchers can view the surface of the rubber as if they were walking across a lunar landscape.

Research and industrial practice

The insights provided by these different instruments allow the development team to analyse surfaces down to the tiniest detail. The Special Labs' portfolio of test equipment really comes into its own with new material concepts where standard testing methods are unable to provide a complete, highly detailed picture of the relevant structures. An understanding of the physical and chemical laws and forces at work on the nanometric scale allows developers to make targeted quality improvements rather than relying on empirical experimentation. In the Special Labs, research and industrial practice are thus inextricably linked.







TYRE DESIGN

An industrial design team at Hanover-Stöcken is responsible for creating the tyres' distinctive design, with support from designers in Puchov, Slovakia and colleagues at the Fort Mill facility in South Carolina, USA. This global team designs all of Continental's brands and tyre types worldwide.

There are three aspects that are especially important when designing tread patterns and sidewalls:

1. Since most new tyres are the successors of previous models, their appearance must set them apart from their predecessors by emphasizing the new and innovative features.
2. A tyre's specific features should be immediately obvious to the end customer. As well as being important for product presentation in the media, this also helps tyre dealers to sell the product.
3. The tyre's design must be clearly distinguishable from its competitors and easily recognizable.

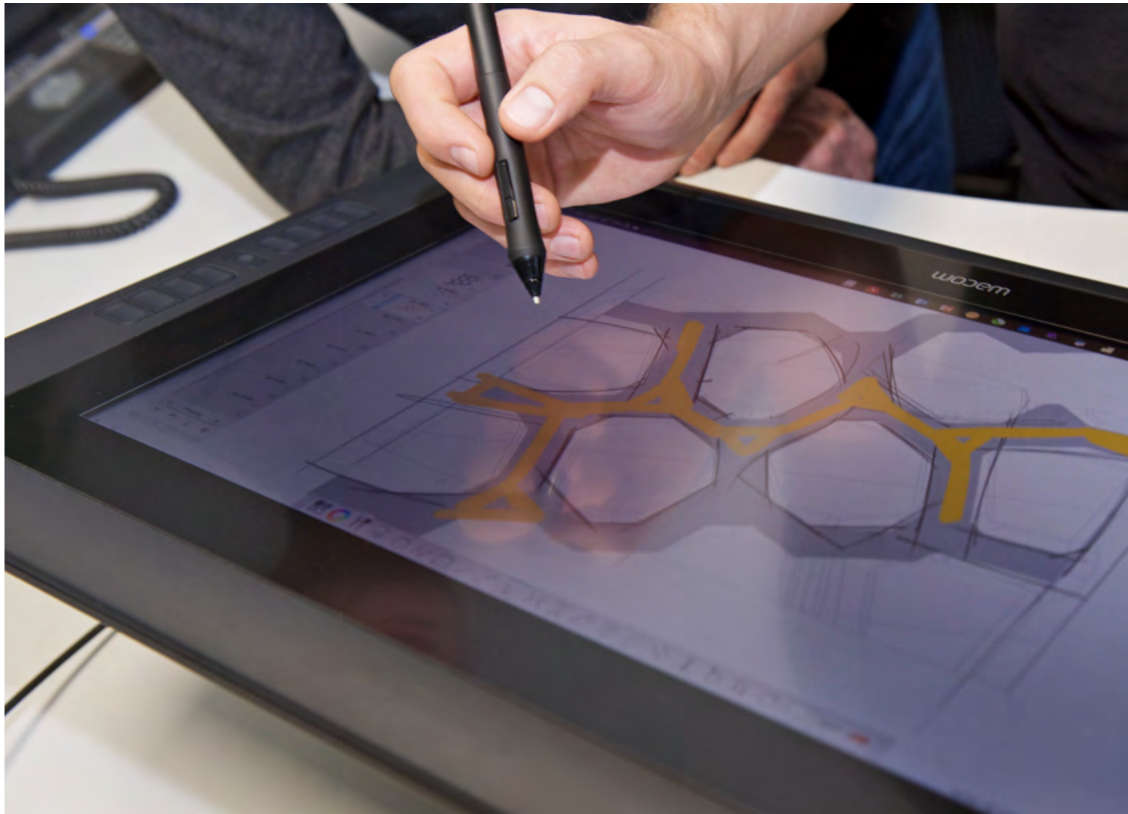
Every year, Continental brings between 15 and 20 new tyre models to market around the world. This means that the team is always working on several products at the same time; each tyre development project takes an average of two to three years to complete.

Design and development

The tyre designers work in close-knit project teams alongside developers, tread pattern specialists, compound engineers and marketing professionals. The creative freedom that the designers are able to exercise is of course limited by the demanding technical specifications that must be met by any new tread pattern. It can be particularly challenging to create a design that is compatible with these specifications; the extent to which the tread pattern can be varied is always determined by a combination of design and performance criteria. The fact that tread pattern performance is tested repeatedly in a series of development loops also provides an opportunity to repeatedly test and optimize the design, as well as to explore different design options.

From sketchpads to 3D printers

Designs are often initially created with a pencil and a sketchpad, before being refined with the aid of graphics programs and converted into 3D CAD models. High-end computer simulations are then carried out to further optimize the tread pattern design. 3D printers have become a standard tool of the trade, used to produce initial hands-on models that designers can work with during the very early stages of a product's development.



CUTTING WORKSHOP

The cutting workshop at Hanover-Stöcken is the only one of its kind anywhere, so the team of experts there are the first port of call for tyre developers all over the world. The cutting workshop is renowned for its exceptional flexibility and the speed with which it can produce test tyres. Virtually every tyre design can be made by hand – a process that is far quicker and more flexible than using moulds due to the considerable amount of work involved with their design and production.

Smooth tyres and series production tyres

The tyre cutters usually start with smooth tyres that are similar to slicks. Alternatively, series production tyres are used as a basis then custom modified. Precision is key when working on the tread, with a margin for error of just a few tenths of a millimetre. This calls for supreme concentration above all else, as a single incorrect cut can ruin days of work. All the cutting knives are produced by hand at a specially designed knife bending station.

From freezing the tread pattern to manufacturing the finished tyre

Once the test tyre is ready, it's time to make the tyre mould. Depending on the complexity of the tread, the costs for a tyre mould can run into five digits for just a single tyre size. Considering the Continental portfolio with all its different brands and sizes spans some 6,000 tyre products, mould production requires a huge capital outlay by each tyre plant. Only once all test series have been completed after three to five years and the final tread pattern has been "frozen", i.e. definitively set, does series production of the moulds for tyre production begin. The rubber compound can be changed again as and when required, but modifying the tread is a far more complex and costly affair. Depending on requirements, CAD-programmed robots that ensure a high level of automation and reproducibility are also used for tyre cutting.

Trade fairs, Tour de France and the World Cup

The cutting workshop's tyres are used in many standard tread tests, while its day-to-day work also includes requests from OE customers for exhibitions and trade fairs, as well as show tyres for events such as the Tour de France and the football World Cup. An experienced tyre cutter will need approximately six hours to cut a summer tyre, whereas a winter tyre with all its fine sipes for optimum grip on snow will require about 40 hours of work. Training to be a Continental tyre cutter takes two years and the job demands great sensitivity, skilled craftsmanship and a very good eye.

TYRE CHARACTERISTICS

The Characteristics Indoor department at Continental's tyre development unit is a DAkkS-accredited test laboratory. Its primary tasks include measuring and verifying dynamic rolling resistance in accordance with EU tyre label guidelines. The EU tyre label works in a similar way to the energy efficiency label for washing machines and refrigerators, assigning ratings from A to E for three tyre characteristics: rolling resistance/fuel efficiency, wet grip and external noise. These label ratings are retested for each new generation of tyres and every product size that becomes available.

All the way to the load limit

Around twenty test methods for car and truck tyres are available for this purpose, analysing the forces produced during tyre operation right up to the load limit. The methods include laser measurement, measurement of the distribution of forces on the tyre during travel using pressure measurement plates, plus load, camber and toe angle testing ("force & moment"), and static tests to check dissipation characteristics for electrical charges which build up during travel.

Flat belt and drum test rigs

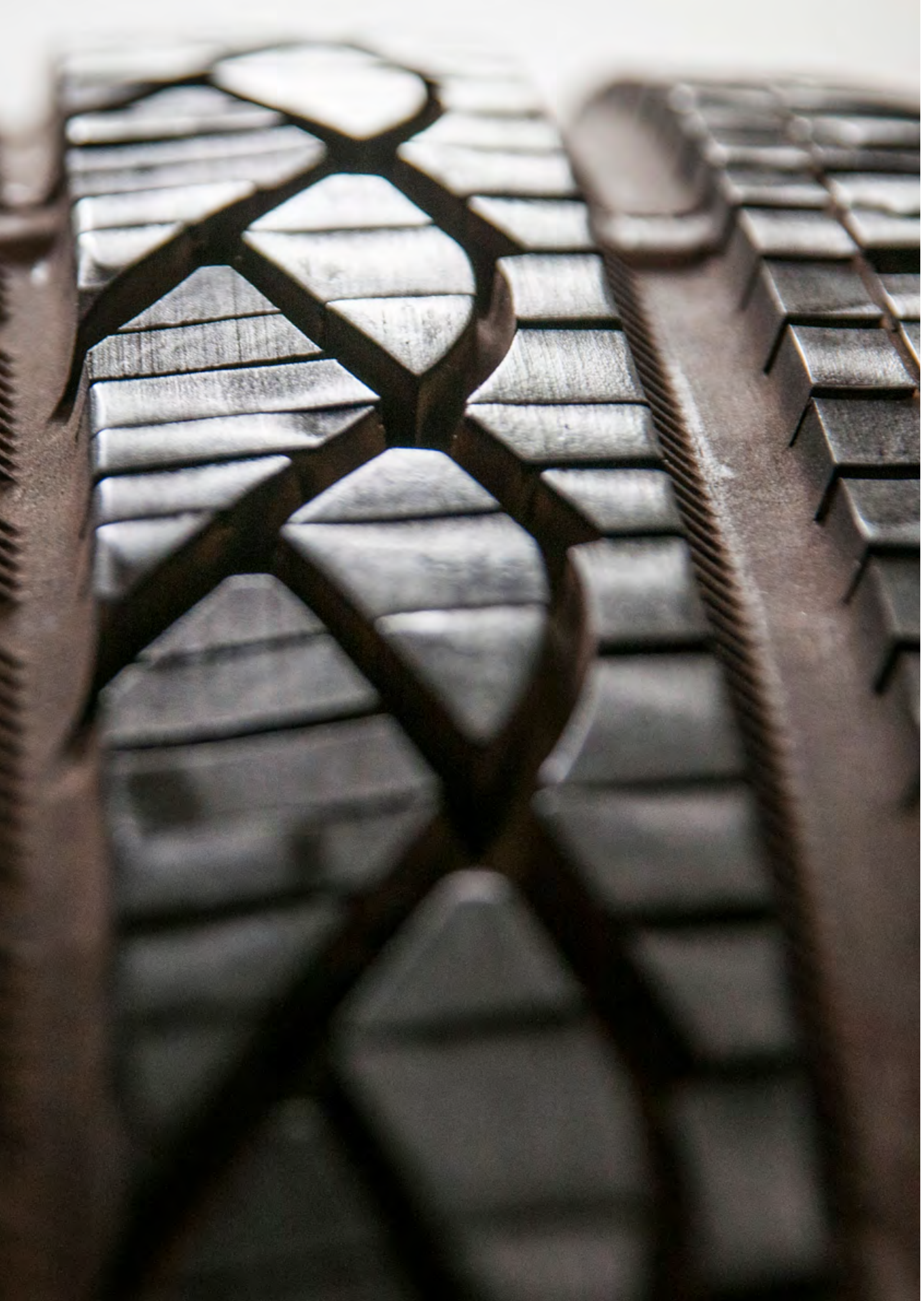
Dissipation resistance testing is particularly important for safety as a moving vehicle can build up a static charge during the journey. The tyres provide a connection to the ground here, acting as a kind of earthing cable. If the tyre has inadequate electrostatic charge dissipation characteristics due to its design, this could lead to uncontrolled static discharges. The highly complex “force & moment” tests with various load, camber and toe angle settings are particularly time-consuming and are carried out on a flat belt test rig. All the other test series are performed on drum test rigs.

“Flat spot” test

The “flat spot” test is equally important for the end user. It provides an indication of possible out-of-roundness after being stationary for a prolonged period, as may happen with motorhome or camper van tyres. This phenomenon can also occur after an extended period of high-speed motorway driving followed by a break. The hot tread cools while the vehicle is stationary causing the shape of the contact patch to change, after which the tyre may feel “out-of-round” until it warms up again.

One of three in the world

The main customers of the Characteristics Indoor department are Continental’s internal R&D departments, which continuously commission material and structural testing at the same time as arranging quality tests for OE customers. The department also works together with manufacturers to develop test methods for new steering concepts, such as multi-link axles, or tests for self-driving vehicles. As well as the lab in Hanover-Stöcken, Continental has set up another facility of this kind at the Puchov tyre plant in Slovakia and a third one in Uvalde, Texas (USA).



DURABILITY AND WEAR

How many miles will a tyre last? How does the tread behave over its lifetime? Does the tyre wear uniformly or unevenly? The staff in the Wear Testing Indoor test department are able to answer these questions. This department has a total of eleven drum test rigs, comprising eight for car and motorcycle tyres and three larger ones for truck tyres. Industrial tyres for forklift trucks, airport vehicles and agricultural machinery can have their wear characteristics tested here too.

The tread surfaces run on rotating drums that simulate a road surface in the test rigs. A maximum of six car tyres can be tested at the same time on the drums, which measure up to three metres in diameter and weigh as much as six metric tons. When the drums rotate at a specified speed, their mass and surface simulate the road surface and driving speed.

Real-world operation in fast forward

These "artificial surfaces" are more abrasive than roads and so they speed up the rate of wear compared with real-world use. The test rig has no unevenness, potholes or varying road surfaces of the kind found on everyday roads, resulting in ideal, reproducible test conditions. The test rigs can model the average annual distance covered by a car tyre in just ten days, resulting in major time and cost savings over outdoor testing on public roads or proving grounds.

A variety of parameters, such as load, tyre pressure and camber, can be set for the individual test positions, enabling a broad spectrum of driving situations to be simulated.

Different forms of wear

A test run can last up to eight days for car tyres and as long as 14 days for truck tyres. The test results give a very clear indication of how a tyre wears under different conditions, showing, for example, whether freestanding tread blocks tend to suffer heel and toe wear or if diagonal wear may occur. The results are fed back to departments such as product development, the OE department and quality management for tyre production, depending on whether testing is being carried out on prototypes, specific tyres for individual vehicle models or random samples from ongoing production. Other R&D departments are also involved, such as the Mixing Lab and Compound Testing Lab.

ENDURANCE TESTING

The standard test is a marathon event in itself: the tyres run in the test rig for over a month – up to 1,000 hours to be more precise – at a speed of 120 km/h. The Endurance Testing department has various drum test rigs that allow several car tyres at a time to be put through their paces in a wide range of test positions.

Endurance tests in many different test positions

A large number of drum test rigs conduct endurance testing on truck tyres in a variety of test positions. There are also high-speed test rigs for testing car tyres at speeds as high as around 400 km/h. Further test machines capable of applying high loads are available for testing truck tyres and special agricultural and industrial tyres.

Endurance testing doesn't look at how a tyre wears but what it can actually withstand: When and why does it reach the limit of its structural endurance? In addition to high-speed testing, there are also burst, bead unseating and plunger tests, which are carried out to ensure and document compliance with all regulatory requirements.

On top of this, internal testing beyond the limits of structural endurance is also routinely carried out.

The Endurance Testing department

Endurance Testing is one of the largest test departments within the R&D arm of Continental Tyres. This is where prototypes for new tyre developments as well as random samples from ongoing production are taken for endurance testing. This involves a preliminary inspection of the tyre before it is fitted onto a special wheel rim. The tyre is conditioned, i.e. pumped up to the required test pressure and brought up to temperature, before being mounted on the test rig for testing at the desired load and speed. The tyre is regularly inspected over the course of the test run, after which it is sent to the internal analysis group where it is not only cut open, but also undergoes X-ray or CT scanning. The investigations shed light on where the tyre failed structurally and why.

Way beyond the speed symbol

The high-speed tests are of particular interest for car and van tyres. These involve testing the tyres under conditions that comfortably exceed their speed rating symbol in order to ensure that the tyre is fit for the market. The test results are evaluated by the tyre analysis specialists and fed back into the tyre development process.

The findings from endurance testing provide vital guidance in product development, helping to make sure that work is progressing in the right direction when creating future tyre models. Quality management testing for current models accounts for around 25 to 30 percent of the test runs. Most test jobs originate from product and platform development and mainly involve original equipment tyres and tyres for the replacement market.

NOISE, VIBRATION & HARSHNESS

How can tyre road noise be reduced? Finding this out is the job of the team working in the Noise, Vibration & Harshness (NVH) Lab. Tyres are responsible for around 50 percent of the noise produced when driving. The ideal “silent” tyre is a heavy and smooth slick. In wet conditions, however, this type of tyre performs very poorly in other criteria compared to a well-balanced summer or winter tyre.

How testing is carried out

The tyres run at different speeds on various road surfaces in an anechoic chamber while highly sensitive microphones record the noise generated. The contact pressure between the tyre and the surface it is running over can be varied in order to simulate different vehicle weights.

Special software is then used to analyse two aspects of the tyre's NVH performance: 1. The road surface-dependent rolling noise emitted directly by the tyre into the environment. Here, the analysis checks whether the tyre noise meets or even falls below the statutory noise protection limits (EU tyre label). 2. How well does the tyre absorb vibrations without transmitting them into the vehicle interior via the body? NVH Lab staff work closely with the tread designers and are consulted as soon as it is time to evaluate the initial versions of a new design. However, noise performance is affected by other aspects too: the properties of the tyre casing, the sidewall, the density of the material and the tyre's weight.

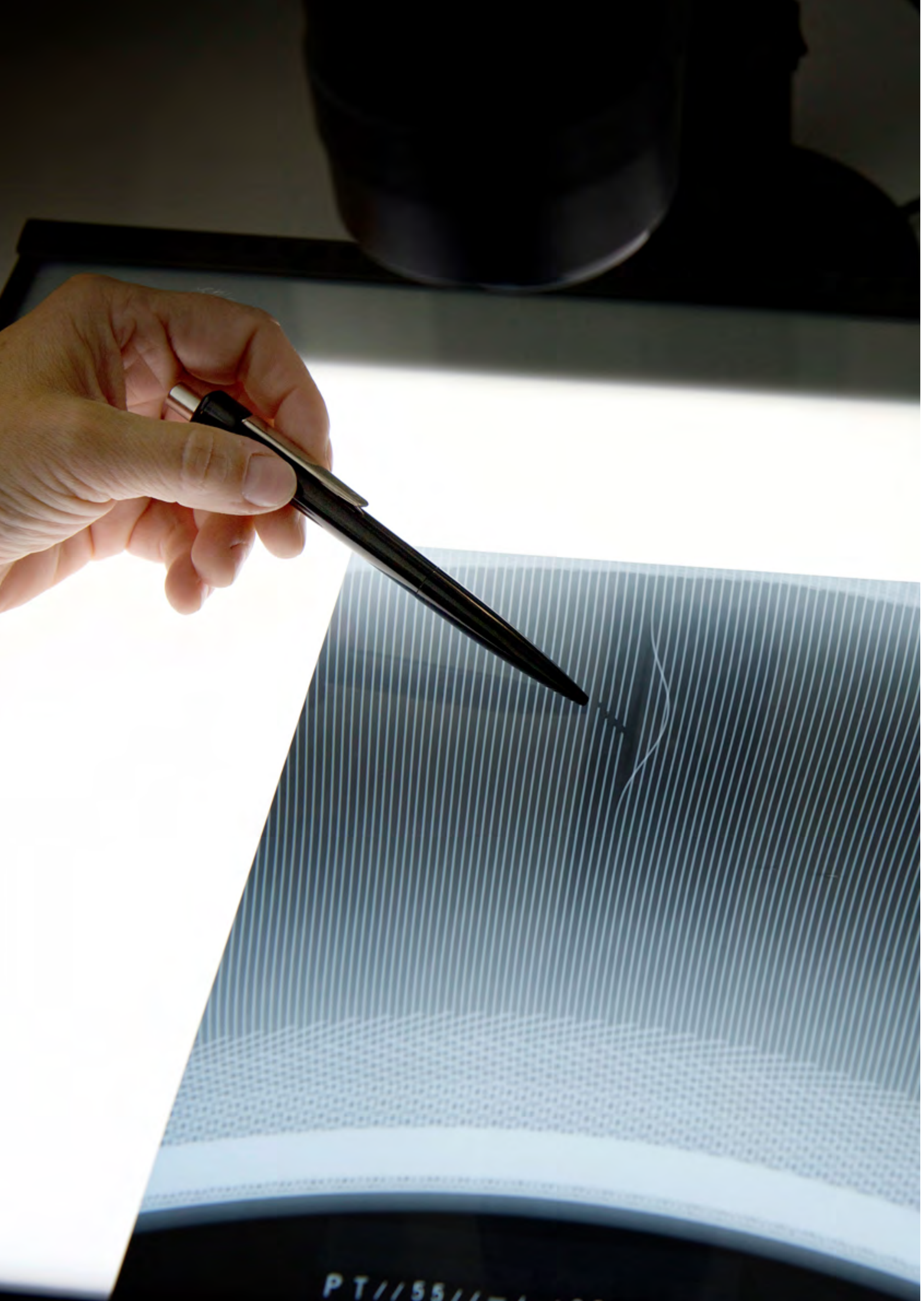
Electric mobility enters the limelight

Tyres for electric vehicles account for a steadily increasing proportion of noise tests. Such tyres must have exceptionally low rolling resistance along with a lightweight design in order to increase vehicle range. The NVH Lab provides insights into how to resolve possible conflicting goals in the product development process.

Sound design around the world

Besides calculating quantitative noise levels, the NVH Lab is also responsible for sound design. Indeed, it is not just the volume of a noise that determines whether it is perceived as obtrusive, but also the nature of the sound it makes. One well known example of this is the distinctive "howling" sound made by truck tyres at certain speeds and on particular road surfaces. The sound designers also manage to transform the higher levels of noise from winter tyres into a more pleasant sound.

Since sound is perceived very differently from one continent to the next, tyre noise is customized for the markets in Asia and North and South America. So, not only does the NVH Lab interface with the other R&D departments at Continental, it also actively addresses customer wishes brought to its attention by marketing and sales teams around the world.



X-RAY AND CT TYRE ANALYSIS

The group of non-destructive testing units, comprising shearography, computed tomography and X-ray analysis, form another department at Continental Tyres R&D.

Shearography is a laser-assisted, optical measurement technique for detecting irregularities in the tyre such as air bubbles. X-rays and CT scans are used to take an even deeper look into the material. Hanover-Stöcken is the only site within the Continental Group to boast the requisite facilities, complete with analytical laboratories. The physical infrastructure in the cellar of one of the buildings there has 125 cm thick steel-reinforced concrete walls and provides the necessary radiation protection.

Continental has been using computed tomography since 1997. The process has been continually improved over the years, as a result of which the time required for a 2D scan has been cut from one hour to just three minutes.

The linear accelerator has sufficient power to "see" right through even thick-walled truck tyres without image artefacts, meaning that even the tiniest deviations in the tyre's construction can be identified. Another standout feature is the ability to simulate various operating conditions by replicating different loads and tyre pressures during the scan. This makes it possible to conduct series of comparative tests with different tyre specifications.

With such a large number of tyres presented for testing, the team is constantly being confronted with new challenges – and their work never fails to yield surprising results. The testers help the product developers better understand the ins and outs of the material combinations so they can optimize their simulation models. Support is also provided for other business areas through investigation of technical products such as hydromounts for Vibration Control.

DESTRUCTIVE TYRE ANALYSIS

Tyres are in for a tough time here! The Destructive Tyre Analysis department takes the whole tyre to pieces to identify, analyse and evaluate faults in the casing, the sidewall or the overall tyre structure. The tyre is dismantled into its component parts using pliers, wire cutters and tyre cutters before undergoing forensic examination.

A fully standardized diagnostic procedure means that seven Continental sites around the world can carry out these investigations and share their knowledge with one another.

It takes two years for an analyst's fault-finding skills to become entirely dependable. It should make no difference whether the tyre has been analysed at Continental's diagnostic lab in Malaysia or at the Hanover-Stöcken site because the same high standards apply at all seven such locations around the world.

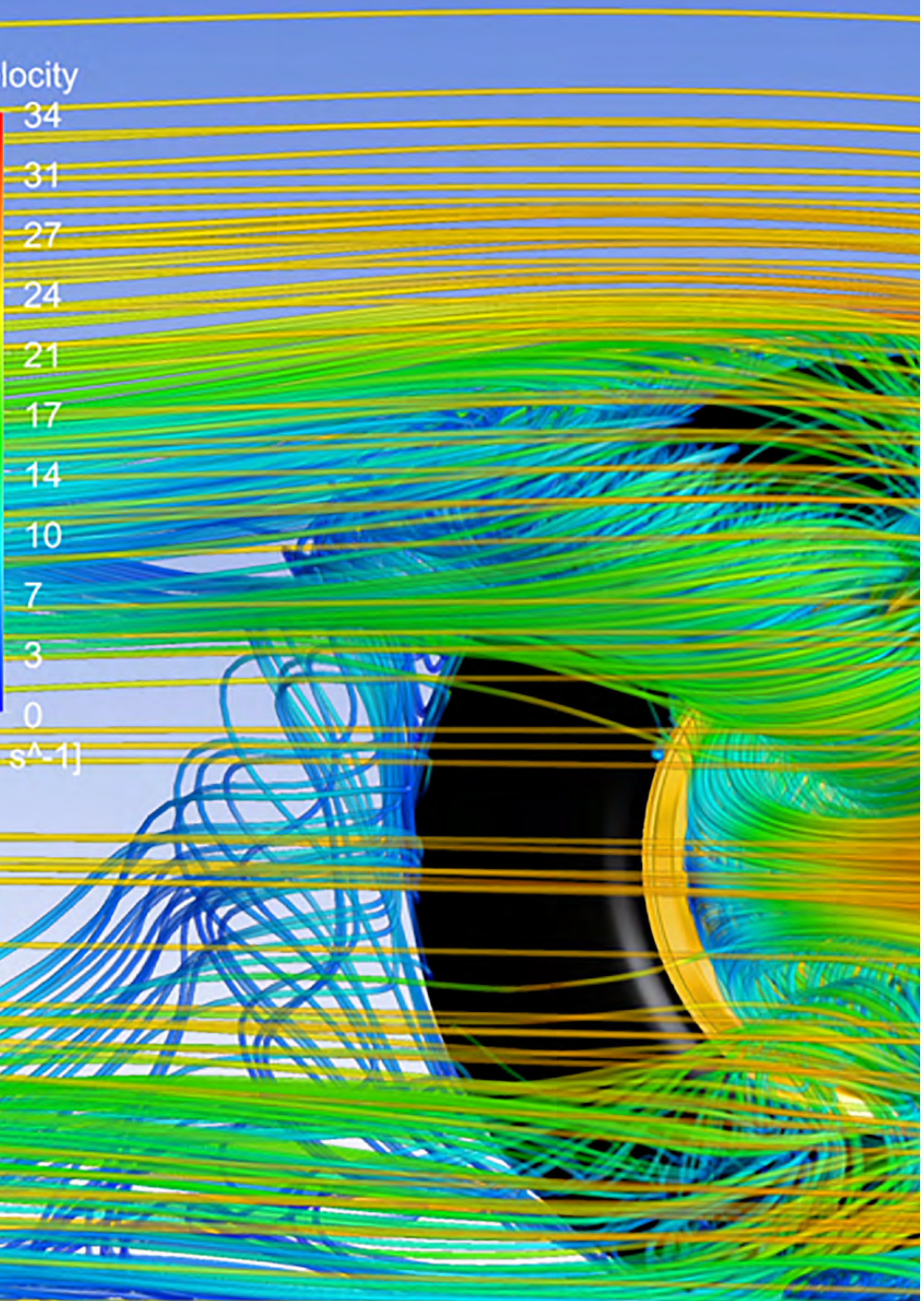
The diagnostic procedure in detail

The diagnostic procedure basically involves three steps:

1. An initial investigation of the complete tyre is carried out. The location of the fault is recorded and marked.

2. Samples are obtained for the structural investigation, mainly by means of hard physical work. After all, it takes considerable force to peel off a tread with pliers and the same applies to removing the bead using a tool known as the "can opener". The tyre cutters are kept in a separate room. Water-jet cutters for obtaining thin and planar sections form part of the standard hardware. There is a recycling system for recovering the fine particles of sand used in the water.

3. Finally, the actual analysis leading to main and secondary findings is carried out in the diagnostic lab. This also includes the precise measurement of dimensions. Up to six main findings plus up to six secondary findings are recorded per tyre. Findings are classified on the basis of a catalogue that is updated annually.



SIMULATION

In the past, simulations were mainly used in the tyre sector as an additional product development measure to complement testing. Today, simulation methods have become far more reliable and precise. But is it now possible to predict all characteristics of the finished tyre reliably and accurately?

Rubber is a complicated material. Due to its viscoelastic nature, replicating it – especially in combination with other equally intricate component parts of a tyre – is a very complex task. Predicting its behaviour is therefore more complicated than for metallic materials. However, with the help of more digitalized development processes and increasing hardware performance capabilities, simulation methods have achieved a level of maturity that allows them to be increasingly used as standard procedure in the tyre sector as well.

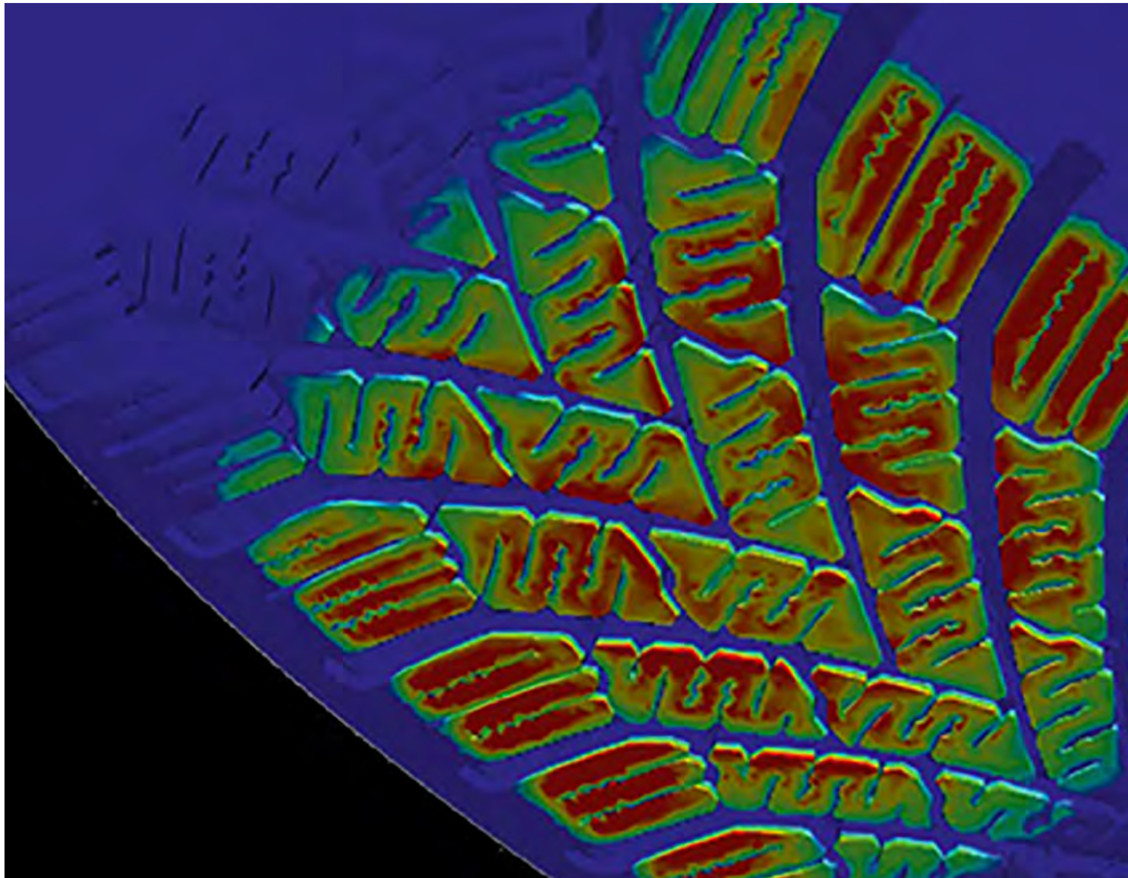
Consequently, simulations are now in a position to always compete with other test methods. The method ultimately selected will be the one that is most effective and delivers the best results. There are tyre characteristics which are relatively easy to test but difficult to simulate, while others can readily be simulated but testing would be a very laborious process. The rolling resistance of an existing tyre can be determined relatively quickly by drum testing, for example, whereas a simulation method would involve far greater expense. However, if the aim is to predict wear under specific driving conditions for a tyre that has yet to be developed, testing would be extremely costly. In this case, simulation would be the preferable option.

Simulations for evaluating performance

There is currently a strong trend towards using simulation methods to assess "additional performance", particularly in relation to handling dynamics and the associated tyre characteristics. The ideal scenario for tyre development would be if simulations could provide a preview of what a tyre's construction should look like for it to achieve the desired characteristics, in the best possible way, using existing technology. In the real world, simulation is not yet sufficiently accurate in all areas. Added to which the product's characteristics are always subject to a certain degree of variation due to the materials used. This explains why today's development process still has to include one or two loops using actual components in order to evaluate performance.

Growing number of target approvals

In recent times, there has been a sharp increase in the variety of vehicle models produced by the automotive industry. On top of this, each model comes with a choice of many different sizes of tyre to satisfy varying customer preferences. Consequently, the proportion of original equipment developments ("target approvals") is rising, despite the overall volumes involved possibly remaining the same or even declining. This results in great complexity and, in particular, huge expenditure on testing – for tyre and vehicle manufacturers alike. Given the likely smaller volumes involved, both parties have no option but to cut their development costs per target approval substantially while maintaining the same high standard of quality. Virtual development therefore offers enormous potential, enabling a vehicle manufacturer to combine a tyre model with their vehicle model so that it can be tested and fine-tuned on a computer or in a driving simulator.



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