Development of Fibratech composite automotive wheel technology — wheel testing methods

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Abstract

The development of composite technologies is being observed across numerous industrial sectors and is primarily driven by the need to enhance the functional properties of components and products. Carbon fiber composite materials, once primarily utilized in the aerospace industry, are now increasingly adopted in other sectors, such as the automotive industry. The article presents a schematic procedure for testing composite automotive wheels, with particular emphasis on load assumptions, the description of physical testing methods, and the discussion of results that define successful test performance and determine the safety level of subsequent use of the component as part of the vehicle's unsprung mass.

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Introduction

The development of composite technologies has been observed across numerous industrial sectors and is driven primarily by the need to enhance the functional properties of components and products. Carbon fiber composite materials, once primarily utilized in the aerospace industry, are now increasingly adopted in other sectors, such as the automotive industry. However, such an intersectoral transfer entails a new set of requirements. In contrast to the aerospace industry, the automotive sector imposes distinct constraints, including cost sensitivity in manufacturing, the necessity

Conflict of interest

None declared.

for serial production, and specific aesthetic expectations. These factors—alongside the fundamental principle of lightweight design—were among the key challenges addressed by the Fibratech team in the design and development of composite automotive rims [1, 2]. This article focuses on the testing methodologies and strength-related assumptions adopted by Fibratech, which directly influenced the development of the first rim prototypes introduced to the market.

Mechanical strength testing of composite automotive rims — discussion and results

The Fibratech team initiated the design process of composite automotive rims by first gathering the relevant strength and durability requirements.

It is important to emphasize that a vehicle rim, as a component of the suspension system (i.e., part of the unsprung mass), has a significant influence on driving safety. Notably, there is currently no fully standardized testing protocol for such components. Strength and performance requirements vary depending on the target market—specifically, the aftermarket versus the Original Equipment Manufacturer (OEM) sector. In general, it can be stated that the performance criteria for aftermarket components are typically less stringent than those for OEM parts. The Fibratech team considered the requirements of both markets but ultimately based its development approach on aftermarket specifications. This decision was not driven by ease of implementation but rather by the desire to demonstrate the competitive advantages of the product. A rim that is excessively heavy or overly robust is not, from an engineering standpoint, an "ideal" rim. According to industry experts, such as Superior Industries, an ideal rim is one that fulfills all requirements and, upon exceeding them, fails in a controlled manner—for instance through cracking—rather than continuing to carry unnecessary structural mass.

The testing scheme for composite automotive rims developed in accordance with document [3] is presented in Figure 1, along with a discussion of selected tests.
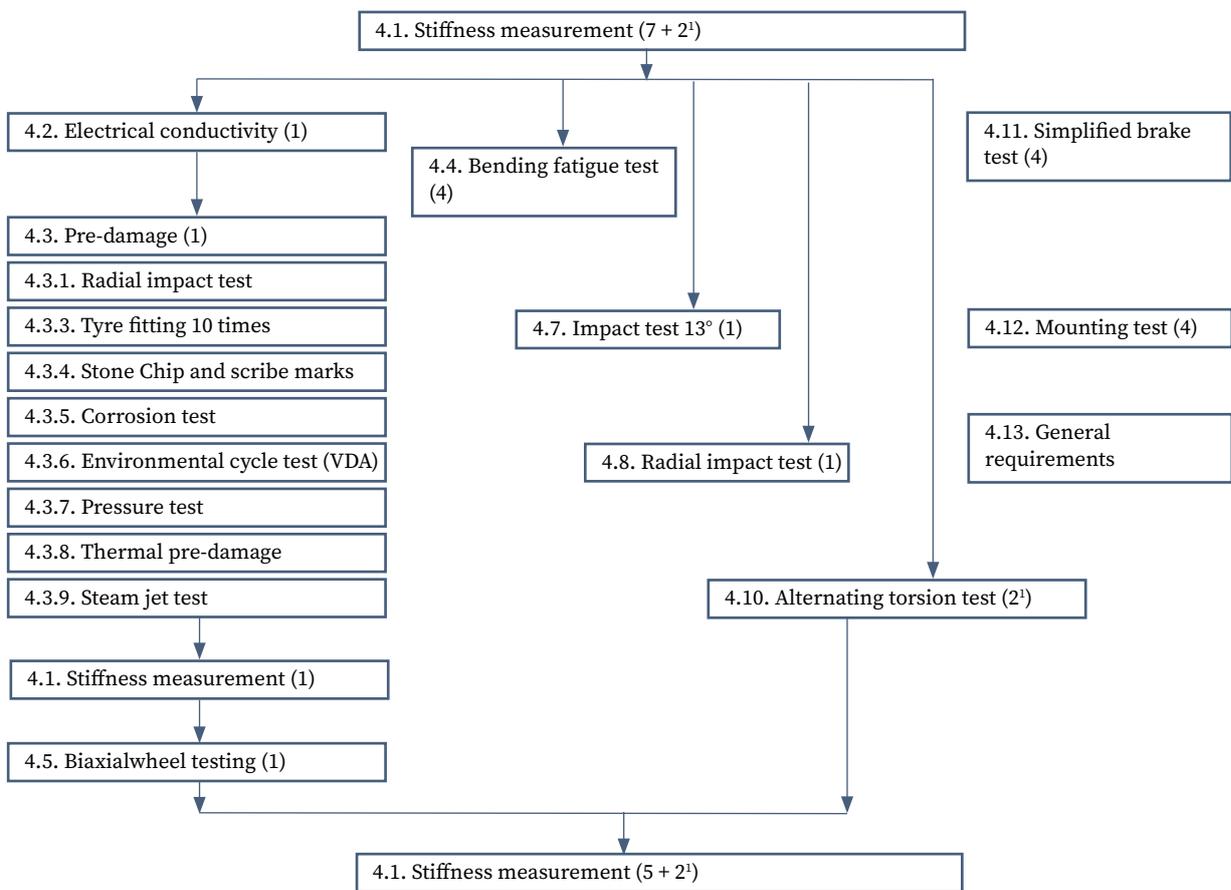

Figure 1. Overview of test methods for vehicles in categories M1, M1G and N1, N1G [3]

The scheme presented in Figure 1 shows the non-destructive testing points (from 4.2 to 4.5) and the destructive tests, where a positive or negative result is assigned based on the damage criteria.

The stiffness measurement describes an attempt to verify the stiffness of a wheel design and its characteristics (Figure 2). In the axial direction, measurements should be taken, if possible, on spokes located 90° from each other. In the radial direction, one measurement should be taken between two spokes near the valve hole, and an additional one at a spoke. The assessment for structural failure requires that testing be repeated at least twice at each position (cf. overview of test methods), i.e., on the wheel in the condition as delivered, after pre-damage, and after strength testing [4].

Testing is carried out without tyres, using the intended wheel fastening elements and the specified tightening torque at room temperature (RT = 20°C ± 5°C). The clamping device, including the wheel connector, shall be sufficiently stiff to prevent deformation during loading. A full cycle shall be completed, starting with a pre-load (20 N), followed by the application of the test load (radial or axial), and ending with unloading to 20 N.
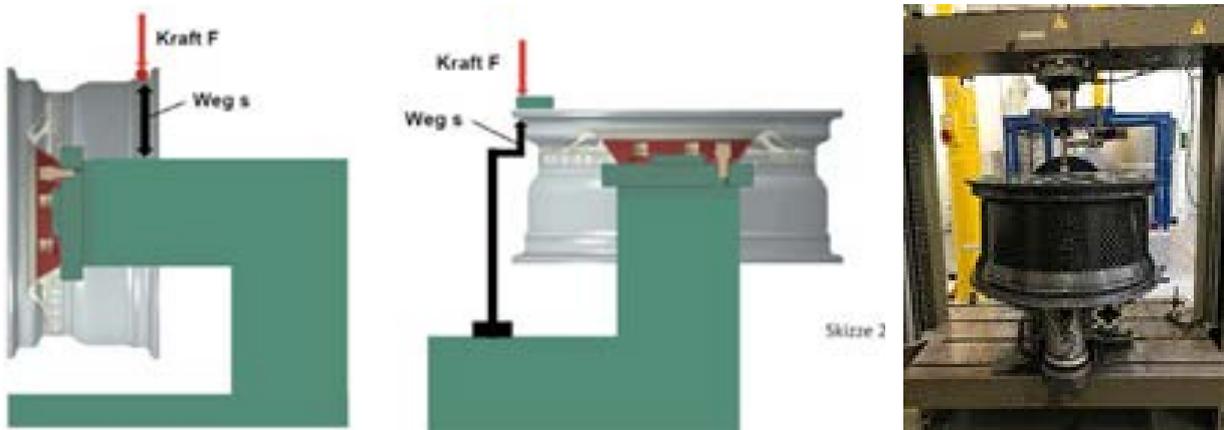

Figure 2. Radial and axial stiffness measurement scheme [3] with testing photography

After defining the stiffness characteristics (serving as a kind of test reference), testing can continue. In this case, the procedure is divided into two columns: one column called "pre-damage tests" and a separate testing path mainly for damage-resulting tests. Pre-damage tests include the radial impact test, which is a well-established test described in detail in the standard AK-LH08 (and presented in Figure 4). This test is carried out between the spokes at the valve hole and simulates driving over a pothole or another obstacle (Figure 3). The tyre inflation pressure is set to 2.5 bar.

$$E = f \cdot F_r \tag{1}$$
$$f = 1.15 \tag{2}$$
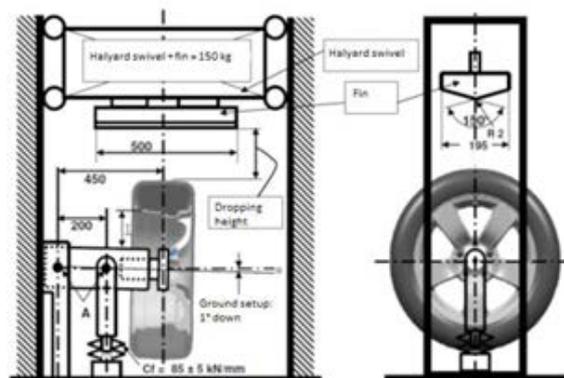
where:
F_r—wheel load [kg]
E—energy
f—coefficient

Figure 3. Schematic sketch of the impact test setup and physical testing jig [3]

Figure 4. Testing jig for stiffness measurements and impact testing designed and prototyped by Fibratech

Figure 5. Wheel after impact testing- visible cracks

As presented in Figure 5, the plastic deformation [unit I] that may occur at the location of impact can be determined by measuring the difference (before/after) at the inner rim flange below the tyre seat and documented [5, 6].

The next, and one of the most important, tests is the rotating bending test (Figure 6). The bending fatigue test simulates the lateral forces that act on the wheel during cornering. Each wheel is rigidly clamped to the test rig and subjected to a rotary bending moment M_{bmax} (3), applied via the wheel contact surface in an appropriate manner (e.g., using a loading arm with a flange that has the same connecting dimensions as the intended vehicle). The wheels are clamped on the inner rim flange using a clamping ring. If alternative clamping methods are used, their equivalence to the standard clamping method must be demonstrated. The wheel fastening elements are tightened to the torque specified by the vehicle manufacturer and are re-tightened after approximately 10,000 load cycles. The dimensioning equation is given in Equation 3.

$$M_{bmax} = f \cdot F_r (\mu \cdot r_{dyn} + e) \qquad (3)$$

where:
M_{bmax}—reference moment for load stages [Nm]
F_r—permissible static wheel load [N]
r_{dyn}—dynamic tyre radius of the largest intended tyre [m]
e—offset [m]
f—increase in wheel load factor [–]
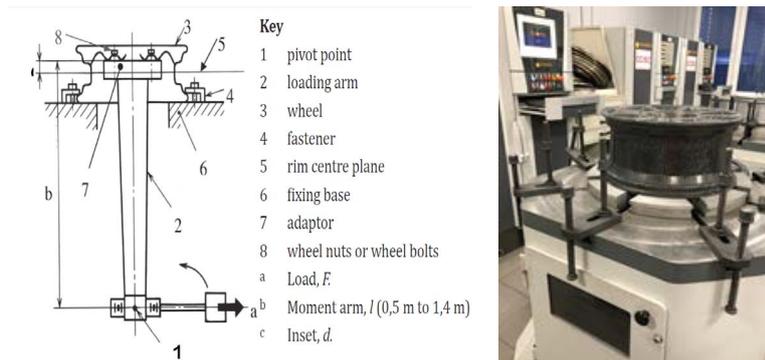μ—coefficient of friction between the tyre and the road 0.9

Figure 6. Schematic representation of a rotating bending test jig and a photograph of the corresponding Fibratech apparatus

Testing is carried out according to the criterias presented on Table 1 (a new wheel should be used for each load stage).

Table 1. Rotating bending test parameters

Vehicle category	M1, M1G and N1, N1G
Wheel-load increase factor f	2.0
Target load cycles per minute	As high as possible, but beyond self-resonance

Load level	75% M_{bmax}	50% M_{bmax}
Number of test specimens	≥ 1	≥ 3
Target load cycles	≥ 200,000	≥ 1,800,000
Permissible drop of tightening torque	≤ 30%	
Failure criteria	Structural damage, crack, fracture	

Figure 7. Example of a rotating bending test protocol

Top section: "Wyliczona wartość graniczna"—Calculated limit value, "Droga wychylenia górna granica"—Upper limit of deflection, "Moment gnący dolna granica"—Lower limit of the bending moment, "Moment gnący górna granica"—Upper limit of the bending moment, "Prędkość obrotowa górna granica"—Lower limit of rotational speed, "Prędkość obrotowa górna granica"—Upper limit of rotational speed.

Mid section: "Osiągnięto zatrzymanie pośrednie"—Intermediate stop reached, "Procedura badania jest kontynuowana po przerwaniu"—Testing procedure is continued after the interruption.

Bottom section: "Przekroczenie górnej granicy wychylenia"—Exceeding the upper limit of deflection.

Figure 8. Example of a rotating bending test curve. The x-axis shows the angular velocity values, and the y-axis shows the bending moment

This is one of the most critical tests, as it is closely related to the axial stiffness of the wheel. The testing protocol, including the wheel failure procedure, is presented in Figure 7. Potential damage to the wheel rim is assessed and documented (with the results shown in Figure 8). The level of damage to the wheel rim after the test does not allow for further use, and the rim must be scrapped [1, 4]. This fatigue test is performed for each new design and prototype, as well as for selected wheels at regular intervals (every n-th wheel) during serial production.

The next critical test, which is closely related to the results of the rotating bending test, is the biaxial test. This test is based on an existing test program. The basic program consists of a synthetic load cycle derived from European operating conditions. It includes various load cases, such as driving in a straight line on rough road sections and motorways, as well as sharp right and left turns.

It is also important to mention the test that evaluates the wheel strength under high motor torque. Currently, especially in electric vehicles, this load scenario has become an important component of the overall verification process, since the torque of an electric motor is not related to rotational speed (RPM) in the same way as in internal combustion engines. The tangential forces acting on the wheel during braking and acceleration are simulated in a vibration fatigue test. Two wheels shall be tested for each load stage. Each wheel is rigidly clamped to the test rig on one rim flange and suitably loaded, for example via the intended brake disc or other fittings, with an alternating test torque M_T (4). The wheel mounting elements are tightened using the torque specified by the wheel manufacturer. The dimensioning equation is given in Equation (4).

$$M_T = f \cdot F_r \cdot r_{dyn} \tag{4}$$

where:
M_T—alternating test torque [Nm]
f—increase in wheel load factor
F_r—permissible static wheel load [N]
r_{dyn}—dynamic tyre radius of the largest intended tyre [m]

Testing is carried out in line with the criteria presented in Table 2.

Table 2. High motor torque test parameters

Vehicle category	M1, M1G and N1, N1G
Wheel-load increase factor f	1.0
Min. number of load cycles at 100% M_T	If required
Min. number of load cycles at 90% M_T	$2.0 \cdot 10^5$
Min. number of load cycles at 45% M_T	$2.0 \cdot 10^6$
Number of test specimens	> 2
Permissible drop in tightening torque	≤ 30%
Failure criteria	Crack, fracture, structural damage

In addition to the tests listed above and selectively discussed, car manufacturers almost invariably require wheel suppliers to perform:
- additional tests (for example, extended corrosion resistance assessments or clash analyses),
- more stringent acceptance criteria for the standard tests mentioned above (for instance, Volvo is known for its elevated pass thresholds in the rotating bending test).

All this results in higher testing costs, but also ensures a certain level of safety.

Conclusions

In the design of automotive rims, a wide range of structural and strength-related constraints must be taken into account, which inherently limits the so-called "design freedom" in terms of visual aesthetics. Assuming that the initial geometry consists of a fully closed front face of the rim, an analysis of the aforementioned testing guidelines allows the identification of geometric configurations that are permissible and likely to meet rigorous performance criteria. The use of anisotropic materials, such as carbon fiber composites, not only enables significant weight reduction of the rim structure but also offers the potential to achieve entirely new aesthetic qualities that are difficult or impossible to realize with conventional aluminum wheels.

Acknowledgements

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