Technical Information

Aluminium Disc Wheel Bodies for Rail Traffic

OTTO FUCHS

Forged Perfection

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The limited partnership of OTTO FUCHS - founded in 1910 - is a leading globally active company whose products set trends in the aerospace, automotive and construction industries as well as in the industrial technology.

Based on in-house material we manufacture forged, extruded and ring-rolled products of aluminium, magnesium, copper, titanium and nickel alloys for customers who require safety, low mass, reliability and durability.

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Aluminium Disc Wheel Bodies for Rail Traffic

In times of rising energy costs, it becomes all the more important to reduce the unladen weight of vehicles, also for rail transportation. Accordingly, aluminium as an engineering material is growing in significance, especially in this segment. For instance, many carriage bodies have been manufactured as all aluminium integral structures for many years. The advantages of this structure are its low weight, the minimised assembly time, and often the reduced costs.

On the other hand, steel still predominates in the bogie. Here too, there are a great many components that can essentially be designed in aluminium. Yet reducing the bogie weight, and above all the unsprung masses, not only helps to save motive power, but has a decisive effect on performance and rail load [1].

Recently, the railway industry has intensified its efforts towards reducing the unladen weight of railway vehicles, including the use of forged aluminium components in the bogie as well. The solutions implemented to this end often require component geometries that can be obtained only after a complex production process involving multiple hand and die forging operations. Some examples are bogie suspension systems, spring pads, and coupling parts [9].

Forged aluminium parts for bogies

With over eighty years of experience in the development and production of high quality forged aluminium components for safety applications, OTTO FUCHS supports its partners as a competent source of expertise on the aerospace, automotive, and railway sectors.

Railway Wheels with Forged Disc Wheel Bodies

Forging blank for an aluminium wheel disc

When considered in terms of forging complexity and econo-mical efficiency, the most interesting weight saving solution takes the form of the aluminium disc wheel body, whose axisym-metrical geometry can be obtained with a single press stroke for efficient and therefore low cost production. Compared with other applications practised to date, this wheel disc represents the optimal relationship between additional costs and reduced weight. Above all else, this reduction in weight gives rise to a considerable saving in motive power [2;7].

In the end, these advantages have been instrumental in esta-blishing forged aluminium wheels on the passenger car, com-mercial vehicle, and aircraft sectors for decades.

Further Advantages of Forged Aluminium Railway Wheels:

1. Reducing the unsprung masses helps to raise ride comfort and lower the dyna-mic radial loads acting on the vehicle when it passes over obstacles on the rail [1].

2. Owing to theis lower modulus of elasticity (one third of steel), aluminium wheel discs exhibit greater flexibility for better absorption of shock loads [1]. For these reasons, there is also less expected wear on the tyres and less short corru-gation and ovalisation.

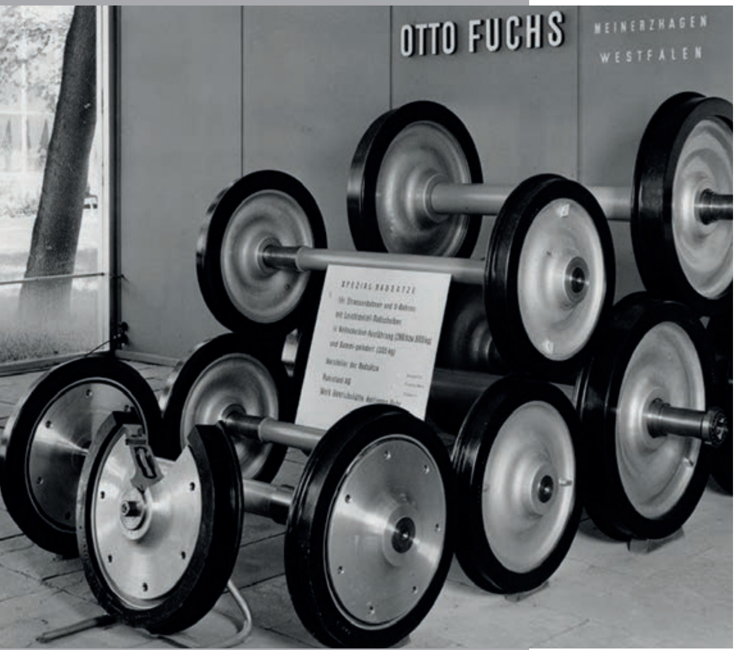
3. At the join between disc and tyre, the lower modulus of elasticity exhibited by aluminium gives rise to a completely different distribution of shrinkage stress marked by a considerably lower stress level in the tyre. This reduces the risk of fracture, above all on worn tyres. This may also have a positive effect on the in-service values. An additional effect is less running noise than equivalent steel designs [1;2;3;6].

Owing to their lower hardness and wear resistance than steel, aluminium wheels are made of two parts consisting of an aluminium disc wheel body and a separate conventional steel tyre. In this system, the steel tyre absorbs the complex loads on the wheel contact point (Hertzian contact pressure, friction heat, wear).

On the other hand, the wheel disc is subjected to two loading components. The first consists of purely static mechanical loading generated by the initial shrinkage stress at the axle-boss or disc-tyre join, plus a second set of dynamic components exerted by the wheel load and transverse forces.

This design principle gives rise to two different versions: the first an unsprung, rigid variant of disc and directly shrunk fit tyre, and the second a rubber sprung variant.

Design Principle of Aluminium Wheels



Various wheelset designs with aluminium wheel discs (1960s)

Basic Concept:

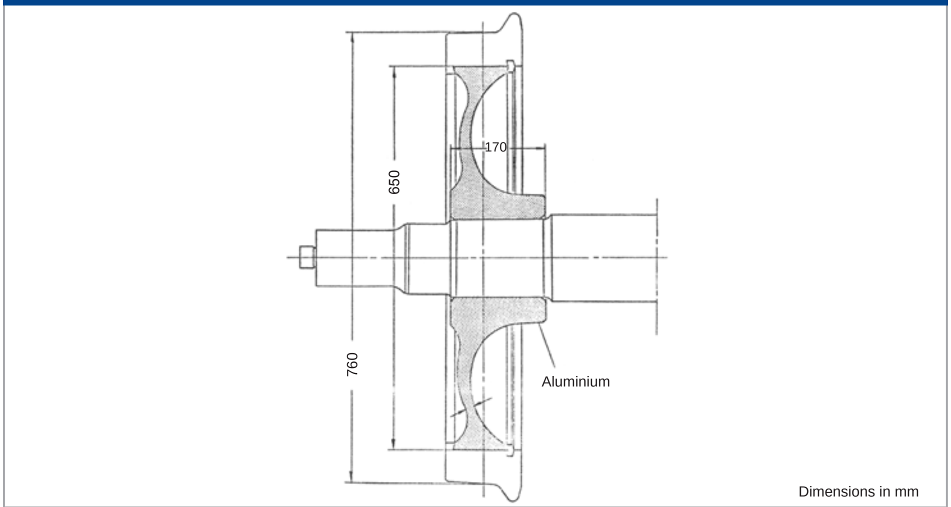
Owing to the low hardness and wear properties of aluminium, the functions of the wheel disc with boss and the functions of the tread must be assigned to different materials in their own, separate sections. In many cases, the ideal solution for the complex loads on the tread takes the form of pearlitic steels. This gives rise to a tyred wheel as the underlying concept. There are two completely different options for the design of tyred aluminium railway wheels.

The Unsprung Wheel:

This consists of an aluminium wheel disc with a directly shrunk fit steel tyre. This solution represents the most economical method for saving weight and is used in lieu of solid or tyred steel wheels, for example for suburban or mountain trains, etc. Investigations conducted by Hamburger Hochbahn on wheels with 860 mm rolling circle diameter confirmed a weight saving of 80 kg compared with conventional steel wheels [3].

In an EU funded research project, prototypes of a trial wheel (rolling circle diameter 920 mm) weighed 75 kg less than a solid wheel of forged steel [6]. All in all, the savings amount to about 50% of the wheel disc's weight.

Unsprung Wheel of the Köln-Bonner Eisenbahn ET 212

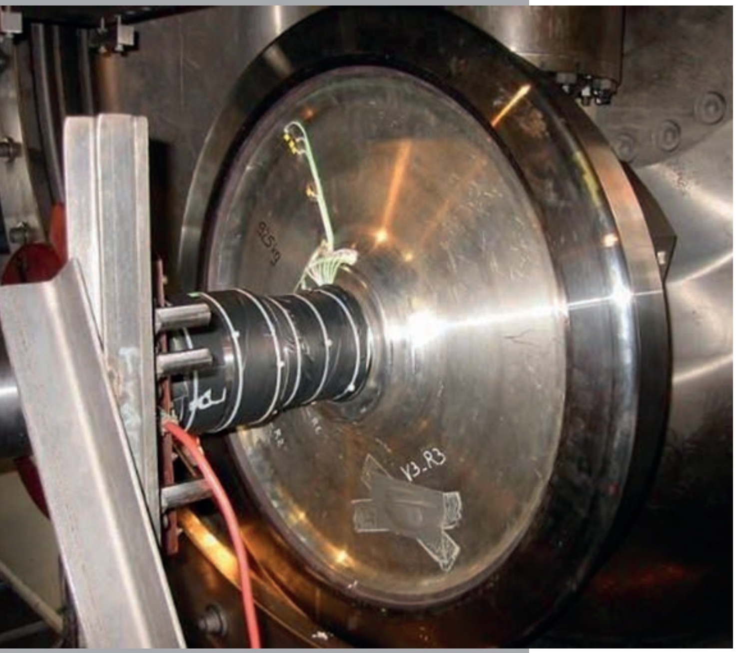


Dimensions in mm

The Rubber Sprung Wheel:

This features a rubber pad between the wheel disc and the tyre. It is used primarily in slow and regional services. In terms of price, rubber sprung wheels with aluminium wheel discs are viable alternatives only where equivalent steel designs are otherwise used. Investigations into a range of applications returned a weight saving of for example 59 kg per wheel on underground trains [3] and 100 kg per wheel on standard gauge trains for a rolling circle diameter of 920 mm [5].

Shrink Fit between Tyre and Wheel Disc



Composite wheel of aluminium and steel
on a two axis wheel test rig (FH LBF Darmstadt)

The unsprung wheel is made up of a wheel disc with a conventional shrink fitted tyre. The correct shrinkage allowance is of crucial importance if the shrink fit is to exhibit adequate load bearing capacity and service life, and the wheel disc the required operational resistance. The lower modulus of elasticity exhibited by aluminium requires larger shrinkage allowances than on comparable wheel disc designs of steel. A general statement cannot be given here for a suitable shrinkage allowance, which depends in addition on the structural flexibility of the wheel disc as well. Too high a shrinkage allowance can induce excessive initial stress in the wheel disc that, superimposed on the operating stresses, can prove detrimental to the operational resistance. Too low a shrinkage allowance, on the other hand, jeopardises the secure fit of the tyre.

In this context, the aluminium wheel can be seen to embody an additional advantage in that its greater flexibility provides better protection against losses in initial stress caused by settling in the shrink fit or the process for rolling on the tyre.

This shrink fit is unnecessary on a rubber sprung tyred wheel with aluminium disc. In this respect, there is no difference between aluminium and steel, whose elastic constants are negligible when compared with that of rubber.

Interference Fit

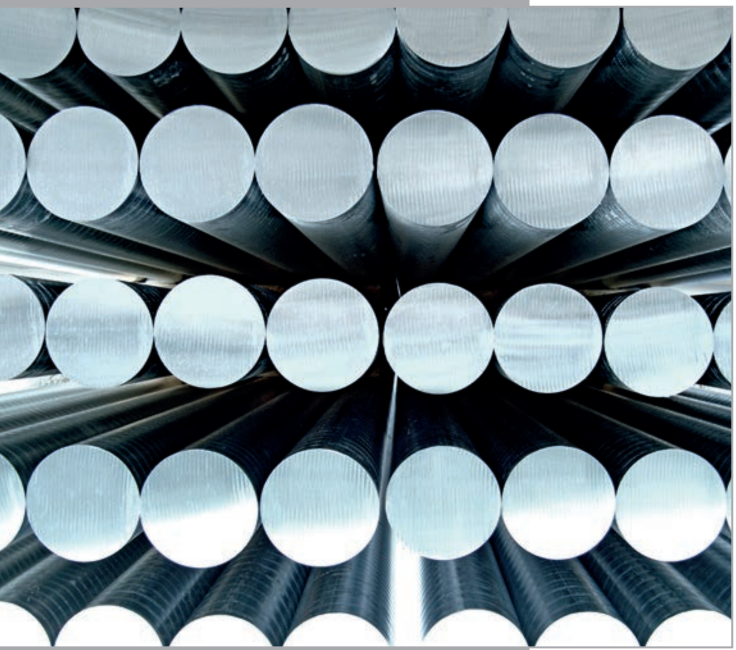
The considerations needed for the correct interference allowances are analogous to the shrink fit between tyres and wheel discs. Aluminium exhibits a greater tendency to gall when pressed on or off a steel axle, but this can be prevented when the axle or boss hole is lined accordingly or oil injection holes are provided in the wheel disc.

Although the different coefficients of expansion for steel and aluminium affect the interference allowance to differing degrees depending on the ambient or operating temperature in the interference fit, the changes in its initial stress induced by the aluminium's lower modulus of elasticity are likewise low and so do not constitute a threat to the fit's reliability. This was confirmed in operating trials [3;4].

One advantage of the aluminium-steel interference fit over an equivalent steel design is the lower edge pressure that otherwise has a detrimental effect on the shaft's service life [6].

Owing to the growing number of low floor vehicle concepts used in local public transport, increasing use is also made of independent wheels with roller bearings. In these cases, the shaft-boss interference fit is replaced with a rolling element bearing. Here too, aluminium disc wheel bodies have been used in the past.

Materials Used



Aluminium forging stock

For many years, the alloy EN AW 6082 T6 has been the established choice both in wheel discs and millions of passenger car wheels and chassis safety components. Besides its good mechanical properties (see Table 1) and excellent corrosion resistance, this material can also be processed with ease in forging practice. The long service life of a wheel disc requires not only operational resistance to mechanical loading, but also superior corrosion resistance to weathering, thawing salt, and other additives that act on the wheel's surface in an industrial or inner city environment. Notwithstanding a corrosion resistance considerably superior to steel, an anticorrosion coating must nevertheless be provided that is resistant in particular to the highly aggressive cleaning agents often used for vehicle care and maintenance [4].

Temper	Yield point	Tensile strength	Elongation at break	Brinell hardness
T6	>260	>310	>10	>90

Table 1 – Performance characteristics of the alloy EN AW 6082 T6

Besides the static strength parameters, OTTO FUCHS KG has also gathered extensive experience in the design of dynamically loaded components and so can utilise this profound know-how of dynamic material properties to size the wheel disc as well.

Furthermore, the OTTO FUCHS materials AS28 and AS29 (EN AW 6110 A) are also available for further optimising the weight of forged aluminium parts. Besides their greater strength, they also offer a toughness and corrosion resistance equivalent to the alloy EN AW 6082 T6. These materials have likewise become established as the preferred choice in hundreds of thousands of components for motor vehicle chassis. The mechanical characteristics are listed in Table 2.

Temper	Yield point	Tensile strength	Elongation at break	Brinell hardness
T6	330-380	360-410	>6	110

Table 2 – Performance characteristics of the alloy EN AW 6110 A

Example Applications

Aluminium-steel wheelset for
the Köln-Bonner Eisenbahn (1960s)

The past has seen a wide and diverse range of implementations with aluminium railway wheels, of which some are still in operation even today. These have shown that the operational reliability of aluminium wheel discs match that of steel when their design makes allowances for the specific properties of aluminium.

The Swiss Federal Railways has been using wheel discs of EN AW 6082 T6 for its Brünig coaching stock since 1944. The top speed of this model is 75 km/h on a 1,000 mm track gauge under a wheel load of 40 kN. At that time, OTTO FUCHS manufactured the discs for about 500 of these wheels. Each wheel disc weighed 37.2 kg, resulting in a weight saving of about 60 kg per wheel compared with a steel design. Also this design featured a steel tyre that was shrink fitted directly on the wheel disc with an undersize of 1.2 mm. New steel tyres are fitted routinely.

In 1960, the Köln-Bonner Eisenbahn started trial runs with OTTO FUCHS wheel discs of aluminium and upgraded new production type vehicles (Vmax/120 km/h, axle load 100 kN, running performance 120,000 km/pa) with wheel discs of EN AW 6082 T6 alloy. This wheel was a two part structure that featured a conventional tyre shrink fitted directly on the aluminium wheel disc. Following optimisations to the component geometries and adjustments to the shrinkage allowances for aluminium, the wheels achieved a running performance of 360,000 km without defects [2].

Since 1965, the Chicago Transit Authority of Illinois has been operating more than 150 vehicles with steel tyred wheels based on aluminium discs. According to studies conducted in 1975, these wheel discs achieved a running performance exceeding 660,000 km without any defects.

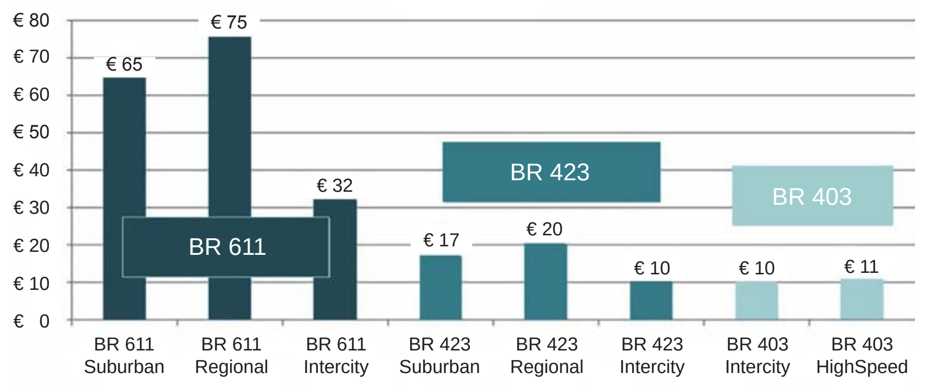
In the mid-1990s, in cooperation with two different wheelset manufacturers, OTTO FUCHS developed rubber sprung wheels for high speed traffic applications. These passed all of the required tests and were approved for trial operations. A series application, however, was not possible following the German Federal Railway’s (DB) decision to substitute solid for rubber sprung wheels in its high speed traffic, although the latter could achieve a 200 kg weight saving per wheelset [5].

Within the same period, a number of similar OTTO FUCHS wheel concepts were realised in local transport vehicles, for example trams in Den Haag.

Application and Development Potential

Aluminium wheel discs can be used above all where weight savings are crucial and the additional expenditure incurred by the use of aluminium is offset by a favourable cost-benefit-ratio. This cost-benefit ratio may involve detailed life-cycle-cost-analyses or adherence to fixed weight specifications that decide on the applicability of a particular product or are associated with certain penalties. Today, LCC based cost-benefit analyses assume a cost advantage, depending on the application, of € 6.00 in high-speed traffic and up to € 46.00 in diesel-powered local transport vehicles per saved kilogram of unladen weight; even greater savings can be attained over the usual service life of 30 years [7;8].

Reduction in Energy Costs per kg over 30 Years (3% Real Interest Rate)

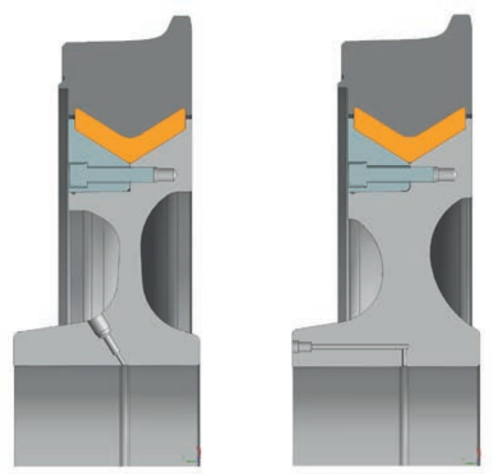


Reduction in energy costs per kg of weight saved over a service life of 30 years for various vehicle types and travel profiles (source: [7])

On this basis, numerous applications for forged aluminium components are economically feasible; the cost-benefit-ratio for aluminium disc wheel bodies is then particularly favourable [9].

A wheel for a modern tram vehicle, with an aluminium construction, has been designed together with a renowned wheelset manufacturer and assessed with regard to the potential weight saving and the anticipated additional costs.

Application and Development Potential



Rubber shock mounted wheel rim-Ø of 680 mm;
left: steel version, right: aluminium version

Component	Steel	Aluminium
disc wheel body	76	34
rim ring (kg)	23	8
total (kg)	99	42

A cost comparison made at the same time found that aluminium components incurred additional costs of aprrox. 32 % compared with steel components, but viewed in perspective, the additional costs in euros are only of the order of a single figure per kg of reduced weight. This is due to the great weight saving of more than 50 kg, which represents an enormously favourable value both in comparison with the LCC reductions referred to above and other lightweight construction measures.

The great weight saving potential of aluminium disc wheel bodies has currently also led to a further series application for a rubber shock mounted wheel of construction type 54 in a modern local transport vehicle. The wheel has a rim diameter of 650 mm and the aluminium wheel body results in a weight reduction of 44 kg compared to a similar part made of steel.

A further advantage of aluminium disc wheel bodies might also be the lower noise emissions; such a noise reduction enjoys high priority in many applications.

Both the literature and the investigations conducted by OTTO FUCHS contain references to the improved NVH (Noise-Vibration-Harshness) behaviour of aluminium wheel discs compared to steel ones [9].

With respect to technical feasibility, there are no fundamental differences between steel and aluminium wheel discs, in particular when their design is the result of modern calculation methods and aids, for example FEM. In addition, forged aluminium parts present a very good surface, that is smooth and unmarred by scale pits, that further facilitate the operationally reliable design of dynamically loaded components. In every case, this lightweight engineering, no matter whether steel or aluminium, requires detailed know-how of the expected operating stresses.

To Sum up

Aluminium disc wheel body for a rubber shock mounted wheel BA 54

As a manufacturer of forged parts, OTTO FUCHS has contributed to a great many developments of aluminium wheel discs, utilising its knowhow in selecting and processing the required materials. In view of today's requirements for local and high speed traffic and the growing obligation to save weight, the basic conditions needed for the development of forged aluminium wheels present a conceivably viable alternative.

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