Queen Mary University of London
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Case Study: Tyre Noise
Group 9

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1. Introduction

1.1. Project Brief

As a result of the existing noise pollution issues on the road, Bridgestone has requested that a more innovative approach be taken to tyre design. In this approach, the primary goal is to design an optimal passenger car tyre that reduces tyre noise. Following research on tyre construction, material, and pattern, a new tyre made with materials designed to solve the problem as well as support the constraints required has been created.

1.2. Background Theory

Tyre noise is one of the most significant contributors to vehicle noise pollution. To reduce tyre noise, many aspects such as the tread design, material choice, and manufacturing process must be revised. The way the tyre interacts with the road surface is altered by the tyre tread design, which is essential in lowering noise levels. The design must minimise vibrations produced during this interaction while optimising the surface area between the tyre and the road surface. Tread designs that have been specifically created to minimise noise levels are a key aspect to consider when aiming to efficiently reduce tyre noise.

1.3 Assumptions and Report Structure

In this report, focus is drawn towards the carcass, tread and inner liner and foam layer as well as finding suitable materials for other components through adequate research. The design of the main components will be determined using a materials index to create an Ashby diagram, that can be used to find suitable materials for a 3-material decision matrix. The assumptions made are that the tyre in question is an all-season tyre for passenger vehicles to target the majority of the population. The average mass of the car this tyre is designed for is around 1.8 tonnes and the minimum load a tyre should be able to withstand must be greater than 450kg. The tire weight is assumed to be 9.07kg based on the average weight of an all-season tire for a passenger car with a 16-inch rim *(How Much Do Car Tires Weigh?).* The subsequent breakdown of our tire's components is as such: Tread: 30-40% of the total tire weight, Carcass: 25-35%, Belt: 10-20%, Inner liner: 5-10%, Cap layer: 5-10%, Inner foam layer: 1-3%, Bead filler: 1-2%, Bead wire: 1-2%.

2. Materials Selection Criteria

To choose the best material for the tyre components, Figure 1 was created to examine all the components and their properties, whilst ensuring their constraints were accounted for.

Figure 1: Table showing the required tyre components and their material criteria.

Parts	Function	Objective	Constraints	Free Variables
Tread	Provides wear resistance and adhesion to the road.	-High Yield Strength -Sound Damping	-High Durability -Wear Resistance	-Material Choice -Tread Design
Cap Layer	Provides additional protection to the tyre's internal structure and improves its durability.	-Improve Traction -Maximise Noise Reduction	-Wear Resistance -Adhesion	-Polymer Composition -Filler Content/ Type -Reinforcement Materials -Tread Pattern Design
Belt	Provides additional strength and rigidity to the tyre's tread area.	-Maximise Tensile Strength -Improve Flexibility -Maximise Stability -Minimise Rolling Resistance -Maximise Noise Reduction	-Durability -Cost -Performance	-Material Choice -Manufacturing Process -Rubber Compounds -Belt Configuration
Carcass	Provides structure and integrity to the tire.	-Maximise tensile strength -Maximise sound absorption	-Lightweight -Flexible -Thickness	-Material choice
Inner Liner	The inner liner prevents any airflow and maintains the pressure in the tyre.	-Excellent pressure retention -Reduce rolling resistance	-Impermeable -Good adhesion to other layers of tyres -Heat resistant -Thickness of inner liner	-Compound Formulation -Surface texture -Material Choice
Bead Filler	Acts as a reinforcement for the rubber and provides proper grip of the tyre to the rim. Eliminates vibration while driving.	-Minimise cost -Maximum Strength -Maximum durability	-High Yield Strength -Good flexibility	-Material Choice
Bead Wire	Retains the structure and the shape of the tyre.	-Minimise tear -Maximise tensile strength -Minimise abrasion	-Adhesive -Stiff -High Yield Strength -Durable	-Material Choice
Inner Foam Layer	Dampen road noise and indoor-felt vibrations.	-Improve road noise damping -Operate at high frequencies	-Thickness -Cost	-Material choice

Figure 2: A decision matrix outlining the deductions made to gauge Polyamide Fibre as the best material choice for the carcass.

Carcass Material Options	Acoustic Velocity (m/s)	Density (kg/m^3)	Tensile Strength (MPa)	Yield Strength (MPa)	Cost (GBP/kg)	Outcome
Cotton Fibre	2.47E+03	1.54E+03	510	225	2.69	Worst Choice
Cellulosics Fibre (Rayon)	1.80E+03	990	420	420	3.04	2nd Choice
Polyamide Fibre (Nylon-6)	1.99E+03	1.14E+03	825	825	2.685	Best Choice

Figure 3: A decision matrix outlining the deductions made to gauge Polyurethane Filter Foam as the best material choice for the inner liner foam.

Inner Liner Foam Material Options	Acoustic Velocity (m/s)	Density (kg/m^3)	Permeability (%)	Cost (GBP/kg)	Outcome
Expanded PS Foam (Closed Cell 0.05)	742	50	2	2.25	2nd Choice
Melamine Foam (0.011)	118.75	10.5	13	9.59	Worst Choice
Polyurethane Filter Foam (Open cell, 0.03)	43.6	30	9	9	Best Choice

Figure 4: A decision matrix outlining the deductions made to gauge SBR as the best material choice for the tread.

Tread Material Options	Acoustic Velocity (m/s)	Density (kg/m^3)	Young's Modulus (GPa)	Yield Strength (MPa)	Cost (GBP/kg)	Outcome
Butyl Halobutyl Rubber (IIR, Unreinforced)	33.9	930	1.10E-03	6.2	1.51	Worst Choice
Natural Rubber, Unreinforced	41.35	950	1.65E-03	24.5	1.62	2nd Choice
Styrene Butadiene Rubber (SBR, 30% Carbon Black)	65.2	1.14E+03	4.90E-03	21	1.19	Best Choice

3. Construction and Design

3.1. Bead Filler and Bead Wire

Bead filler is a particular kind of substance that aids in sealing the bead of a tyre to the wheel rim. The material chosen for this component is unreinforced natural rubber, which is a common choice in industry (*What's in a tire*).

A vital element in the manufacture of tyres is bead wire. Its major purpose is to secure the tyre to the rim while in use to prevent it from slipping. High carbon steel has the qualities needed to support the weight and pressure of a vehicle such as strength, durability, and resistance to deformation, and therefore is the perfect material choice (*Bead-wire* 2021). The steel wire used for this component is typically coated with brass or bronze to boost corrosion resistance and reinforce its contact with the rubber used in tyre manufacturing to reduce the noise coming from the tyre. By coating the bead wire with a layer of rubber, the noise generated during its operation is significantly decreased. Moreover, adding natural rubber can increase the bead wire's durability and resilience, which will ultimately increase its efficiency.

3.2 Carcass and Inner Liner

The carcass is the framework of the tyre that absorbs impact and works to keep the structure of the tyre together (*Tyre structure - tyre guide: Hankook tire UK Official Site*). Usually made from a fibrous material such as cotton fibre, it experiences tension as it works to keep the tyre intact during use.

To determine the material for this component, a Material Index of σ_f/ρ was used, bearing in mind that the carcass was regarded as a cylindrical/spherical shell that was subjected to internal pressure. An Ashby diagram was created, and three optimal materials were picked, as shown in Figure 6.

The material opted for in the making of the carcass was Polyamide Fibre. As shown in the decision matrix in Figure 2, this choice has the most beneficial sound reducing capabilities out of the three options. The use of cotton further ensures the flexibility and doesn't compromise the strength requirements of the component.

The chosen material for the inner liner of the tyre was a mixture of CIIR (Chlorobutyl Rubber) and NR (Natural Rubber) at a 60/40 blend respectively. Also including 50 phr (parts per hundred rubber) of Cloisite C15A as filler in the composition. The main property of the inner liner is its permeability because one of the main purposes of the inner liner is to hold pressure in the tyre and minimise any losses.

To improve damping inside the tyre, the implementation of a layer of foam wedged between the inside tread of the tire and the inner layer is considered. Inspired by the ContiSilent tyre, the addition of a block of foam around the tyre is said to improve noise reduction inside the car by about 9 decibels, by absorbing cavity noise and prevent any vibrations from being transferred from the tyre to the wheel, axle and eventually to the cabin (*Contisilent).* In order to find the right foam for the tyre design, the Material Index used to gauge this material was E/ρ. It was assumed that the inner liner foam was a tie (in essence under tension), with a vibration-limited design. The constraint for this instance is maximum longitudinal vibration frequencies. The Graph derived in Figure 7 showcases the results, whilst Figure 3 determines the Polyurethane Filter Foam as the most viable option, despite the Expanded PS Foam having more green boxes. This is due to its excellent acoustic properties, which are unmatched by the other choices and provide the best dampening results for noise reduction.

The application of polyurethane foam is very simple. It will be sprayed and bonded onto the inner liner at the end of manufacturing. The benefit is that it will not affect braking, handling, and performance in the wet, making it an excellent feature which significantly reduces tyre noise without any drawbacks.

3.3. Cap Layer

In a tyre, the body ply or carcass is topped by a layer of rubber compound known as the cap layer.

The best material to use in the cap layer of a tire that aims to be reasonably cost-effective and noise reducing is silica. Silica is a synthetic substance that is frequently used to make tyres and has great dampening capabilities, which significantly reduces tyre noise. Combining silica with carbon black would improve wear rates drastically, however adding silica to the tyre compound can reduce tyre noise levels by up to 5 decibels (dB) compared to tyres made with conventional carbon black compounds (*Tyre Compounding for Improved Performance,* 2002). This reduction in noise can be significant, as a 3 dB reduction is typically perceived as a halving of the noise level (*Reduce noise in your car with quiet tyres*). The use of silica in the making of the cap layer is also justified by tyre manufacturers who typically use a high-silica compound containing 20-30% silica in the cap layer to achieve the best balance of wet grip, rolling resistance, and noise reduction (*US6959743B2 - tire with silica-rich tread cap layer and carbon black-rich supporting transition zone of intermediate and base layers*).

3.4. Belt

The belt is a layer typically made with reinforcing fabric or steel cords placed around the circumference of the tyre under the tread (*What's in a tire*). The stiffness and damping qualities of the material chosen for the belt are essential for reducing tyre noise. The energy created during the interaction of the tyre and the road can be absorbed and dissipated by the belt material's dampening capabilities, which will lower noise levels.

3.5. Tread

The material chosen for the tread is styrene-butadiene rubber (SSBR) reinforced with carbon black (CB), and Natural rubber (NR) blend. These materials have been chosen as they are commercially available costing £1.19 per KG on average for SBR with CB as shown in Figure 4 and are the industry standard. Comparing to the other standards as seen in Figure 4, it easily outperforms them in strength and cost. Whilst the acoustic velocity is higher, it is still low in general. The CB reinforcement improves the rolling resistance of the car, thus improving fuel efficiency. To further improve SSBR, functional groups can be chemically attached creating Functionalized-SSBR (F-SSBR), this comes with the additional benefits of improving rolling resistance and wet grip (WG) index, respectively. A magic triangle (Figure 9 in the Appendix) shows the indices that are of value to our tire and plots Wet Grip (WG), Abrasion Resistance and Fuel Efficiency (FSE) of all the compounds and mixtures clearly showing that F-SSBR/CNR hybrid outperforms all other mixtures.

3.6 Tread Design:

Figure 5: Tyre CAD

This design consists of a unidirectional groove pattern connecting to one 12mm groove in the middle, with two 0.5 mm grooves on each side. The unidirectional pattern was chosen to improve the grip for an all-seasonal tyre, as well as provide even wear throughout. This design works on the concept of void ratio, by using narrow grooves to minimise the empty space whilst still ensuring grip. To comply with national regulations, the depth of the grooves are around 1.65 to 1.7mm deep to comply with a minimum of 1.6mm (*Tread Depth* 2022). The groove depth is close to the minimum so as to minimise sound, the air trapped under the tyre must have a shallow path to travel through, as a path with more area produces more sound when the air is forced out as the tyre rolls. In order to improve the tyre quality for wear and weather conditions, sipes are also implemented in the design idea as they further improve traction and prevent hydroplaning and interrupt sound waves (*What are Tire Sipes? pros and cons of Siping tires*). A study by Jerzy A. Ejsmont, Ulf Sandberg and Stanislaw Taryma (*SAE Transactions, 1984, Vol. 93, Section 5*) states that increasing the groove width and frequency decreases the impact of tire/pipe resonance. When the grooves are as wide as 12 mm, the pressure gradients (air pumping) that excite the pipe resonances are lower, therefore the main groove in the middle of the tire adopts this concept.

4. Cost

Using the assumptions made in the introduction, an estimate for how much the tyre would cost to produce can be made if we are considering solely raw materials. Based on this we can estimate that the cost of one tire would equate to £18.73, which is incredibly low and beneficial for selling the product at a low price.

5. Conclusion

Overall, the design of this tyre is most likely to reduce noise whilst ensuring that the tyres constraints and initial purpose are met. Each material chosen has the required properties thanks to the use of a decision matrix or literature based on results from industry, and added noise reducing benefits whilst utilising acoustic velocity values helped decide on how much the material will dampen noise. As shown in the decision matrices, the main components are all comprised of materials with low acoustic velocities and acceptable costs, whilst the tread design optimises as many sound reducing components as possible, ensuring that this report was a success.

Appendix

Figure 6: An Ashby diagram showing the chosen materials for the carcass

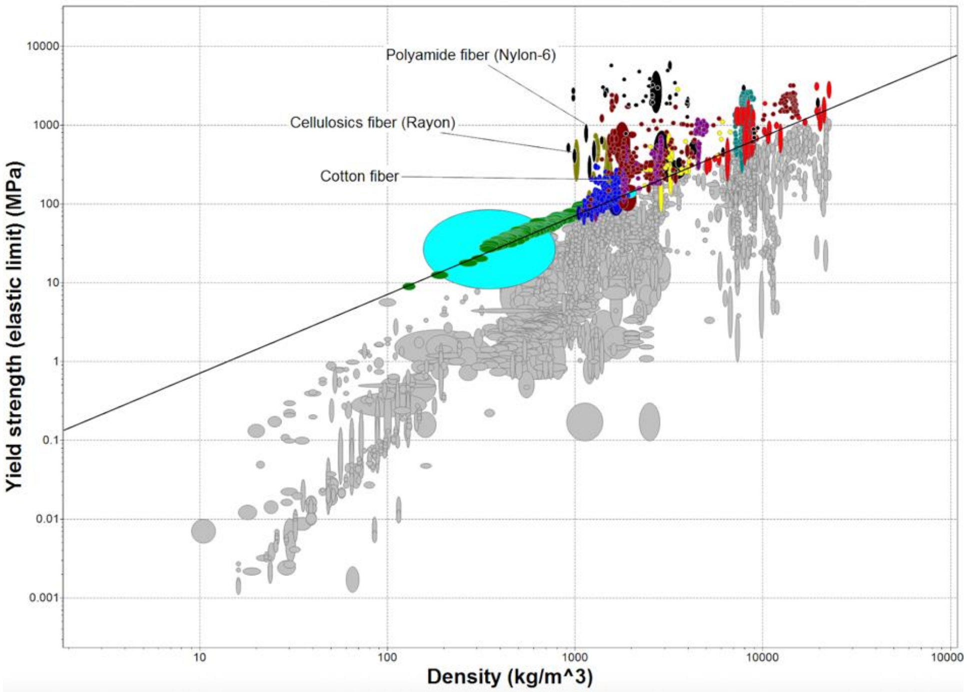


Figure 7: An Ashby Diagram showing the chosen materials for the foam liner

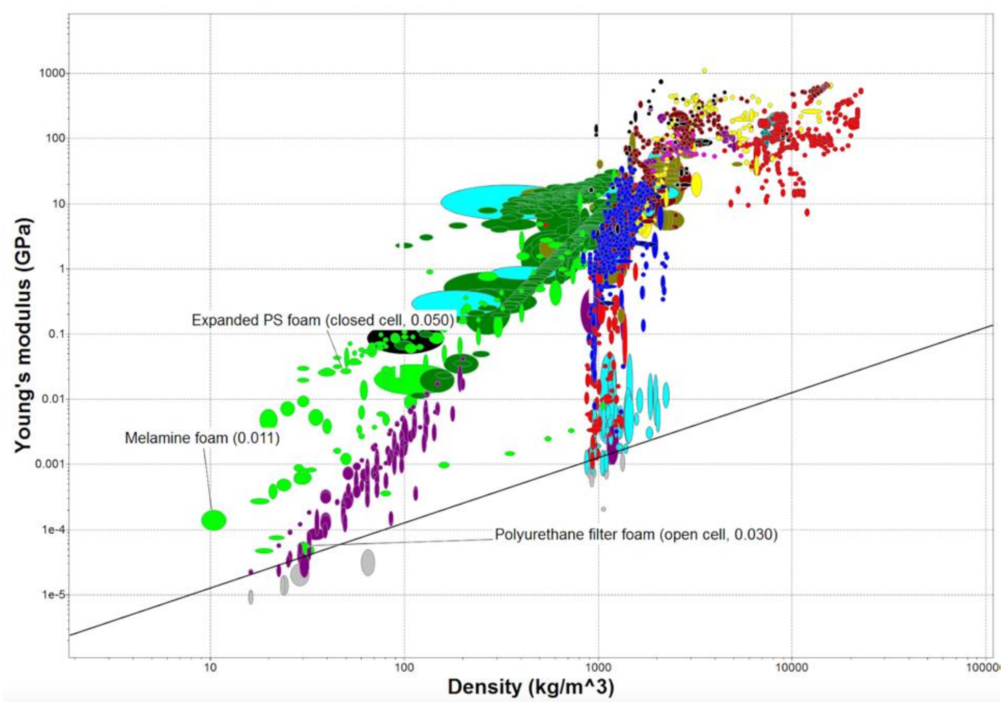


Figure 8: An Ashby diagram showing the chosen materials for the tyre tread

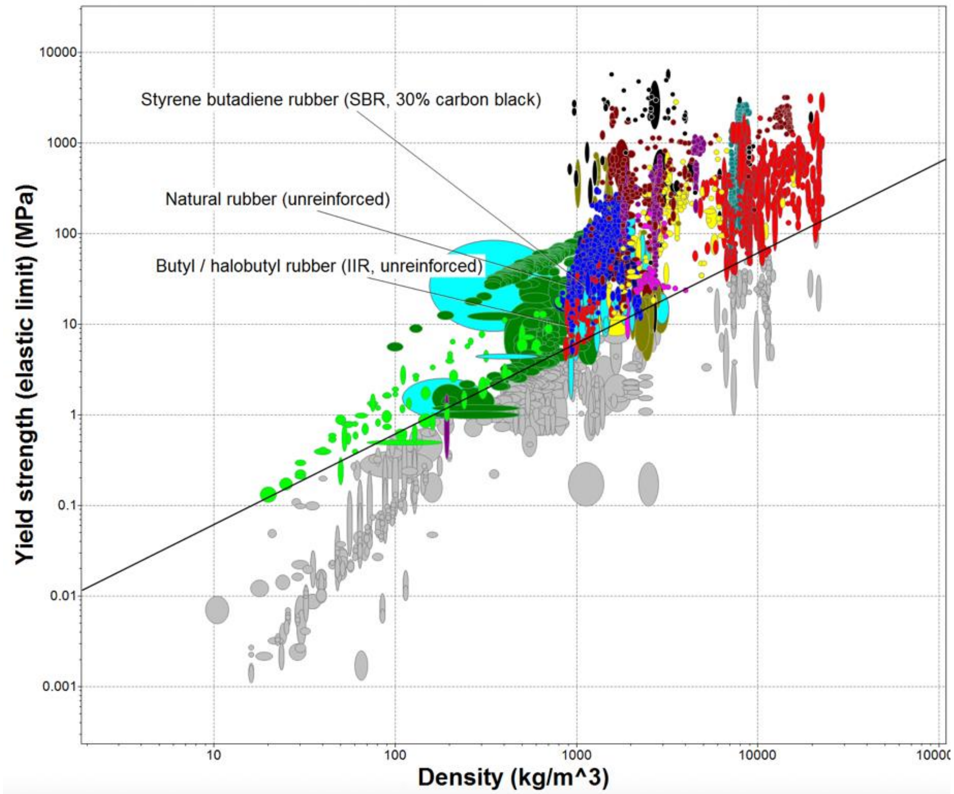
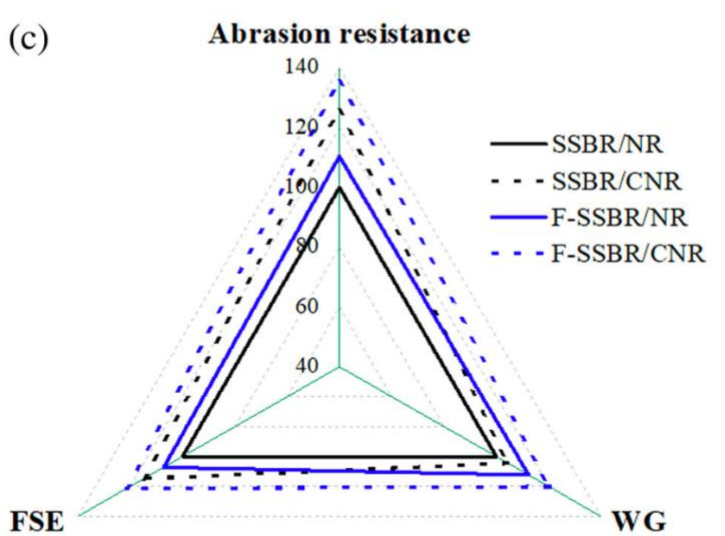


Figure 9: Magic Triangle (*SAE Transactions, 1984, Vol. 93, Section 5*)



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