Group: 2

Case Study: Tyre Noise

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Table of Contents

1. Introduction

Tyres continue to fill an intrinsic role across the world of transport in both the commercial and private sectors. One of the major issues that is faced by tyre manufacturers is noise pollution to both the passengers of the vehicle and surrounding areas - with an estimated 100 million Europeans being affected by harmful noise levels originating from road traffic (European Enviroment Agency, 2017). The project brief requires the analysis and identification of appropriate tyre designs and materials for road tyres that minimise noise while maintaining commercial viability and performance. To achieve this objective, the project team will conduct a broad assessment of each relevant tyre component, considering materials, design choices and processing methods.

2. Design

This section of the report details any design decisions made to reduce noise produced the final tyre. See figure 1 and 2 for a CAD design incorporating all the design decisions detailed below.

Figure 1 – CAD of Tyre

Figure 2 – CAD of Tread

2.1 Tread

The depth of the tread determines the volume of air that can be fit into and subsequently forced out of tread cavity. This means that as tread depth decreases as does the associated noise as a result of pipe resonance (Wing Tat Hung, 2013). Thus, the tread depth must be as shallow as possible while still maintaining legality and sufficient grip. In our case a tread depth around 7.6mm will provide an adequate grip to noise ratio; this depth is in line with similar quiet tyres such as the *Michelin Pilot Sport 5* (Michelin Tyres , 2022). Furthermore, the use of a non-directional, symmetrical tread limits the size and openness of channels, meaning less air can become trapped within the cavity. This minimises noise generated (Ejsmont, 1984). A symmetrical tread has the same pattern across the entire surface, leads to an evenly distributed footprint across the roads surface – resulting in a smoother and more stable ride while preventing irregular wear.

2.2 Jointless Cap Plies

The jointless cap plies are rubber coated nylon fibres located under outer layer of the tyre, providing high speed stability, strength, and wear resistance (UniRoyal Tyres, 2020). To minimise noise as well as improve general performance, a radial ply will be used. This type of ply consists of fibres being aligned perpendicular to the bead, in turn minimising rolling resistance. Reduced rolling resistance has been proven to reduce tyre noise by up to 10dB when used on ideal road surface conditions (SINTEF, 2016). In addition to this, fuel economy and wear resistance both see substantial improvements.

2.3 Foam

The addition of a foam layer to the inner cavity of a tyre is a common step taken across the tyre industry to dampen internal sound and vibration. Foam is most effective around the point of cavity resonance, heavily dampening sound peaks (Simone Baro, 2019). The absorption of vibrations within the tyre cavity prevents transfer to other parts of the vehicle. These benefits make foam an invaluable component when mitigating tyre noise – essentially mitigating internal noise as a concern. Using companies' websites such as Continental, polyurethane foam is the most used material for foam inserts, however, it is unclear which type of polyurethane foam is used (Coninental Tires, 2020).

2.4 Inner Liner

To optimize the acoustic properties for the inner liner of a tire, design choices such as the material used to create the multi layered structure, surface treatments to enhance acoustic properties, and adjusting the thickness can be made. These factors can be adjusted and optimized to achieve the best acoustic properties - balancing noise reduction with other important performance requirements such as air retention and rolling resistance.

3. Material Assessment

The table below details the process of material assessment, providing material indices where relevant.

	Tread	Cap ply	Foam	Inner Liner
Function	- Act as point of contact with the road and generates traction.	- It enhances high speed suitability	- Absorbs tyre cavity noise and reduces body transmission.	- maintaining air pressure
Constraints	- Noise from pipe resonance must be minimal - Meet tread regulation standards	- Must be able to keep appropriate high-speed resistance	-Must be able to absorb tyre cavity noise	- Withstand high pressures and temperatures -Provide air retention and sealing properties
Objective	- Minimise noise - Minimise rolling resistance - Maximise traction - Maximise heat resistance - Maximise wear resistance - Maintain legal tread depth	-Maintain Water Resistance - Maximise wear Resistance -Minimise noise -Maximise Tensile strength or Yield strength	-Minimise flexural modulus -Optimise density -Minimise weight -Be durable -Optimise cell type -Maximise air resistivity	- Sound insulation. - vibration damping. - tyre uniformity. - thickness optimisation.
Free Variables	- Tread pattern - Material	-Material of Cap	-Material of foam -Location of foam	- thickness. - shape and geometry.
Y-Axis Index	Soft, elastic tread $M_1 = \frac{E}{C}$	Yield strength $M_1 = \frac{c}{\sigma_y}$		
X-Axis Index	$M_2 = \frac{E}{HR}$	Tensile strength $M_2 = \frac{c}{\sigma}$		

4. Material Selection

All numerical values are based upon those found in the *Granta Edupack* database and are the average values of the given ranges.

4.1 Tread

Using trade-off graph 1, it can be determined that Perfluoro elastomer (FFKM, Carbon black), Natural rubber (15-42% carbon black) and Polyurethane rubber (unfilled) are all good choices for tread material based upon the decided material indexes. While having satisfactory mechanical properties, Perfluoro elastomer is least suited of the three to be used at tyre tread. The main reasons for this include the comparatively high cost (£184.50 per Kg) alongside the high glass transition temperature (-15°C) – the latter of which making the tread inoperable in low temperature environments. Polyurethane rubber is shown to be a reasonable for the tread material based on mechanical properties. While both average hardness (13 HV) and young's modulus (0.0275 GPa) values are shown to be ideal for traction and grip, such high values could lead to degradation at a higher rate than other options – in effect making the positive of its lower cost (£1.09/kg) fruitless. The best material choice for the tread is the Natural rubber (15-42% carbon black) – this is due to its ideal hardness (7 HV) and young's modulus (0.00525 GPa) values when compared to Perfluoro elastomer and Polyurethane. In addition, it has an acceptable operating range temperature and cost (£1.89/kg).

4.2 Jointless Cap Plies

Through analysis on graph 2, it can be identified that TPC (Shore D55, flame retarded), TPC (Shore D50, Ecdel-type), and TCP (Shore D55) are most suited for use as the cap ply. These materials provide a good compromise between cost, yield strength and tensile strength based on the previously given material index. However, TCP (Shore D55) has a tensile strength (22 MPa) that exceeds the preferred range for a tyre ply (typically 16.5 to 21.5), making it less flexible than is required. Alternatively, TPC (Shore D55, flame retardant) is the most suitable option. This is due to its yield strength (15 MPa), tensile strength (19.2 MPa) and reasonable average cost (£7.16/kg). Furthermore, it is also fire retardant which improves safety in situations like car accidents that could lead to ignition of other possible cap materials.

4.3 Foam

For the foam, a material index is not appropriate to determine the optimum material – instead a decision matrix is used. The data is taken from Database 3 from *Edupack* and external reports.

Material:	Flexural Modulus (GPa)	Density (kg/m^3)	Cell Structure	Cost (GBP/kg)	Porosity	Flow Resistivity
PU Foam (elastomeric, open cell, 0.024)	0.000015	24	Open	5.21	9	7
PU Foam (Elastomeric, open cell, 0.028)	0.000022	29	Open	5.21	9	7
PU Foam (Elastomeric, open cell, 0.065)	0.000035	65	Open	5.21	8	8
PU Foam (Microcellular, closed cell, 0.35)	0.00125	350	Closed	6.165	5	4

As the stiffer a material is, the higher its flexural modulus is, and therefore a lower flexural modulus material would be better for the foam as it is more flexible. In addition, it is generally regarded that open cell foams are more porous, are more flexible and reduce sound better. This also relates to flow resistivity which is the flow resistance to noise per unit thickness of a material (Qiu, 2014), as open cell foams have higher flow resistivity which is shown to increase sound absorption and lower flexural modulus, therefore they are a better choice than closed cell foams. If the density is high enough the sound waves get damped and if it's low enough the sound waves get absorbed, however, if it is too high the waves get reflected and if it's too low the waves are transmitted through the material (Phelps, 2023). An ideal density for sound absorption is 29 kg/m^3 and above. Therefore, the PU foam with a specific density of 0.024 is ruled out as that equates to an average density of 24 kg/m^3. PU foam (0.028) equates to 29 kg/m^3 so it meets the requirement of the density range and subsequently so does PU foam (0.065). The remaining property is very similar, with the price per kg being the exact same. Overall, as PU foam (0.028) is less dense this means that it is more porous which further excels its sound absorption. Pairing this with its lower flexural modulus this would be the better form of polyurethane foam to go with.

4.4 Inner Liner

For the inner liner material, a decision matrix is used. The average values are taken from *Edupack.*

Material:	Density / (kg/m^3):	Cost / (GBP/kg):	Youngs Modulus / GPa:	Compressive Strength / MPa:
PU (Closed Cell)	1.2e3	1.09	0.0028	7.44
Butyl Rubber	930	1.2	0.0011	7.44
PP 56% EPDM Rubber	944	4	0.235	14.4
PP 62% EPDM Rubber	948	3.96	0.14	8.95

Based on the decision matrix and the design goals of reducing noise pollution, PU (Closed Cell) appears to be the best material for the tire's inner liner. Because PU has a low density, it is lightweight and easy to handle during the manufacturing process. It also has a high compressive strength, which is important for the tire's structural integrity. Furthermore, PU can be designed with a porous structure to increase its sound absorption coefficient, which is an important factor in noise pollution reduction. To achieve optimal acoustic properties, the pores' size, shape, and distribution can be controlled. PU is also less expensive than some of the other materials in the decision matrix, making it an appealing option from a manufacturing standpoint. Overall, PU's low density, good compressive strength, and ability to be designed with a porous structure make it a strong contender for the tire's inner liner with the goal of reducing noise pollution.

5. Material Processing

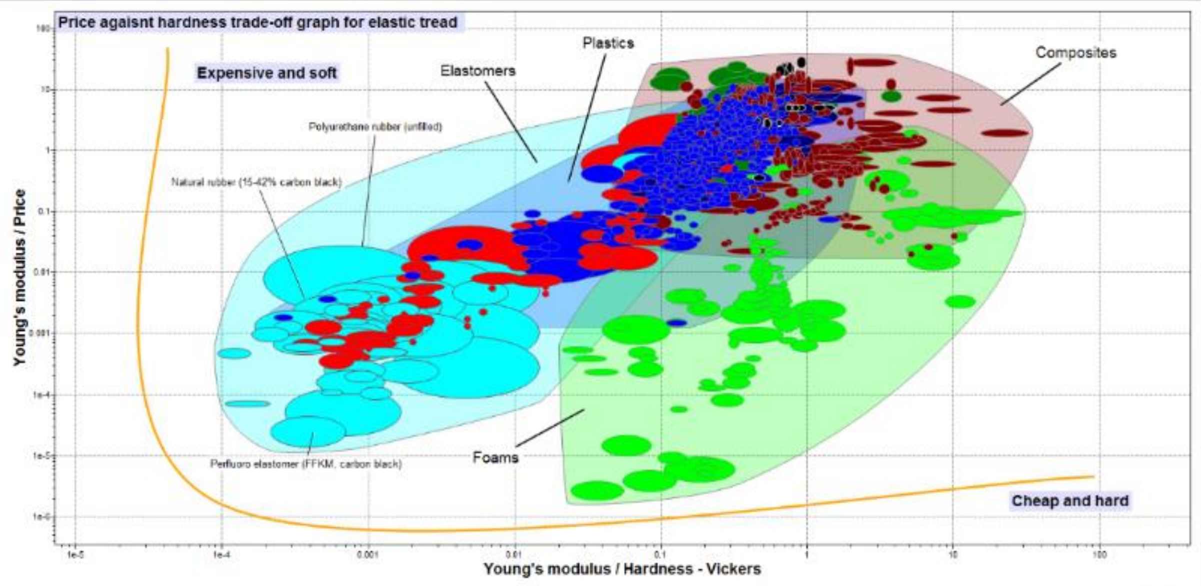
This section of the report covers all the material processes involved with the construction of the complete tyre. For the natural rubber tread, two acceptable processing methods can be identified using *Edupack* – injection moulding and extrusion. Due to the need for long strips of tread rubber, extrusion is ideal as it allows continuous processing. It is also cheaper than injection moulding (especially as batch size increases). When considering the TPC (Shore D55) cap layer, both injection moulding and extrusion are again identified – with extrusion being chosen for the same reasons as the tread. The PU closed cell inner liner can also be extruded due to its nature as a polymer – this allows cheap and continuous processing as sheets in the required dimensions. Finally, the full tyre will be constructed using polymer forging. Each layer is placed on top of one another to create an uncured tyre. This is then placed in a heated mould, which has the tread patten on the outside, with a heated water vessel inside the tyre to preserve the cavity. In terms of the PU foam (0.028) being used for the internal foam, the initial shaping of the foam will be conducted using hot wire cutting. Hot wire cutting can be automated to allow for rapid processing. After being cut, the foam will be affixed to the internal liner of the cured tyre using Polyurethane adhesives, allowing for an extremely thin but strong adhesive that can withstand high temperatures – due to cross linking.

6. Performance Summary

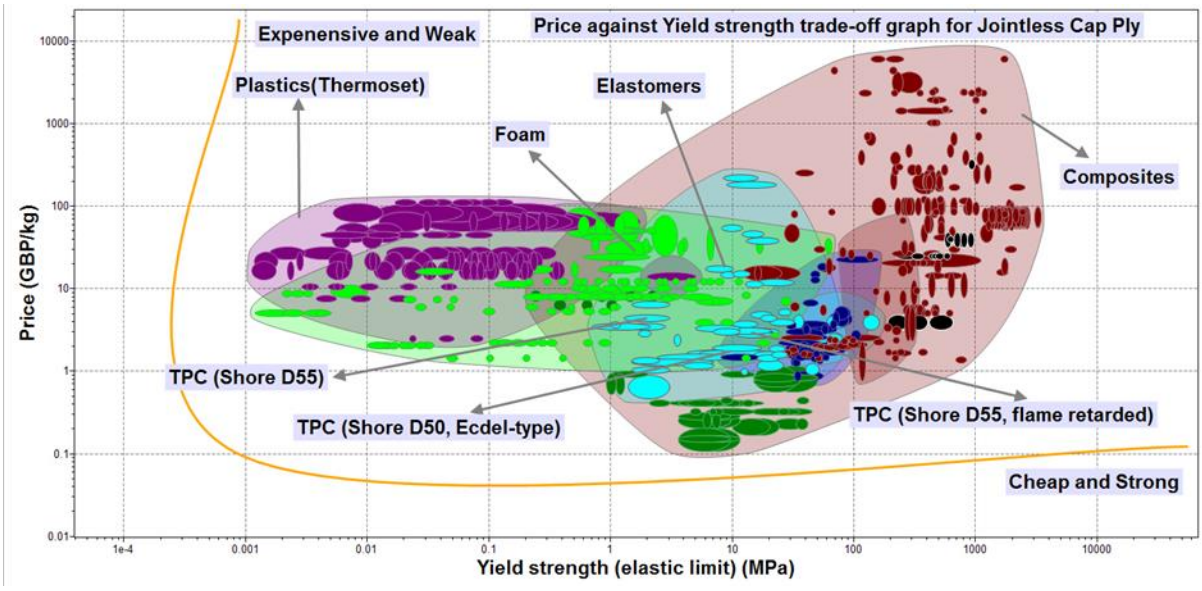
This section of the report covers a complete performance analysis across all required fields. These fields include noise, fuel efficiency, wet grip, wear and cost. In terms of noise, both internal and external noise have been addressed accordingly. The use of a shallow, non-directional symmetrical tread alongside the addition of internal foam, and chosen ply all mitigate noise effectively, being assisted using specifically chosen materials – resulting in adequate traction with a low rolling resistance. As well as assisting in noise reduction, the low rolling resistance – resulting from the chosen ply – significantly reduces the fuel consumption of any vehicle using the tyre. However, a secondary result of these tread choices is low grip in varying road conditions. The tyre would function well in dry weather, becoming less effective under wet conditions as a result of the direction tread – leaving hydroplaning as a significant issue. The wear associated with the tyres would be adequate, mostly due to the hardness of the tread and yield strength of the ply – preventing frictional wear and possible punctures. This serves to improve the cost effectiveness due to having a longer lifetime. In terms of total cost of the altered components, each component covered in this report totalled would be £25.45 (£4.85 for the tread, £15.04 for the cap, £3.65 for the foam and £1.91 for the inner liner). This is far below the cost of other quiet tyres, meaning the cost of the total tyre would still be cheaper than competitors.

Overall, our tyre design meets the stated project brief, mitigating noise while preserving commercial viability – ensuring that performance across areas such as cost, fuel efficiency, wear and grip are all maintained. To improve the tyre design, further considerations of tyre grip across differing weather and road conditions could be made – focusing particularly on minimising hydroplaning without causing an increase in tyre noise. In addition to this, further innovation towards ‘airless’ trye technology could eliminate the issue of internal noise which is inherent to pneumatic tyres.

7. Appendix



Graph 1 – Tread Material Index Graph



Graph 2 – Cap Material index Graph

8. References

Coninental Tires, 2020. *Contisilent.* [Online]
Available at: https://www.continental-tires.com/car/tires/continental-tire-technologies/contisilent
[Accessed 18 03 2023].

Ejsmont, J. A. S. U. &. T. S., 1984. Influence of Tread Pattern on Tire/Road Noise. In: *SAE Transactions.* s.l.:s.n., pp. 632-640.

European Enviroment Agency, 2017. *Road Traffic Remains Biggest Source Of Noise Pollution In Europe.* [Online].

Michelin Tyres , 2022. *Pilot Sport 5.* [Online]
Available at: https://www.michelin.co.uk/auto/tyres/michelin-pilot-sport-5
[Accessed 14 03 2023].

National Museums of Scotland , 2020. *Dunlop Tyre.* [Online]
Available at: https://www.nms.ac.uk/explore-our-collections/stories/science-and-technology/made-in-scotland-changing-the-world/scottish-science-innovations/dunlop-tyre/#:~:text=John%20Boyd%20Dunlop%20(1840%20%E2%80%93%201922,a%20pneumatic%20tyre%20in%201846.
[Accessed 14 03 2023].

Phelps, 2023. *materials for soundproofing and dampening.* [Online]
Available at: https://www.phelpsgaskets.com/blog/material-for-sound-proofing-and-sound-dampening
[Accessed 18 03 2023].

Qiu, X., 2014. Flow Resistivity. In: *Performace testing of textiles.* s.l.:s.n.

Simone Baro, R. C. M. Å. P. C. A. P. F., 2019. Modelling of a lined tyre for predicting cavity noise mitigation. In: *Applied Acoustics.* s.l.:s.n., pp. 391-400.

SINTEF, 2016. *Using low rolling resistance tires to counter traffic noise.* [Online]
Available at:
https://www.sciencedaily.com/releases/2016/09/160928083212.htm#:~:text=Summary%3A,reduction%20as%20traditional%20noise%20barriers.
[Accessed 16 03 2023].

UniRoyal Tyres, 2020. *Tyre Components.* [Online]
Available at: https://www.uniroyal-tyres.com/car/tyre-guide/tyre-knowledge/tyre-components
[Accessed 16 03 2023].

Wing Tat Hung, Y. K. L. C. F. N. C. K. R. L., 2013. *The impacts of tyre hardness and tread depth on tyre/road noise,* Hong Kong: International Institute of Acoustics and Vibrations.