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Material selection report

Engineering Design and Materials (ACHA4001)

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1 Introduction

This report will be centred on the design specification of a modern formula 1 upper wishbone. The wishbones are vital parts of the suspension assembly helping control both lateral and vertical loads while being a vital part of the chassis' structure attaching the wheel hub to the chassis. An in-depth investigation will then be conducted into the material selection and the reasonings of the materials used by the Formula 1 teams along with the various manufacturing processes. Followed by a conclusion on the best suited material and manufacturing process considering various factors such as regulations and costs.

1.1 Aims

- Research the various design specifications.
- Conduct research into the various possible material choices.
- Look into the different types of manufacturing processes used by formula 1 teams to produce the upper wishbone.

1.2 Objectives

- Give an understanding of the purpose and requirements of a wishbone in Formula 1.
- Conclude on the best suited material and manufacturing process.

2 Component design specification

Product Design Specification: Formula 1 Front Suspension Upper Wishbone

2.1 Purpose and Scope

- The upper wishbone is a critical component of the Formula 1 front suspension system, responsible for controlling the vertical movement of the wheel assembly and maintaining proper alignment during cornering and braking.

2.2 Functional Requirements

- Must provide precise control over the wheel's vertical movement while maintaining structural integrity under high loads and vibrations.
- Should allow for adjustability to fine-tune suspension geometry and handling characteristics.
- Must be lightweight to minimize unsprung mass and optimize vehicle performance.
- Should integrate seamlessly with other suspension components and chassis structure.

2.3 Performance Requirements

- Must withstand extreme loads experienced during braking, cornering, and acceleration.
- Should minimize deflection and flex to ensure consistent suspension behaviour and predictable handling.
- Must have low friction to minimize energy losses and ensure responsive suspension action.
- Should have high stiffness-to-weight ratio to enhance vehicle responsiveness and agility.

2.4 Material and Construction

- Material must meet certain specifications required by the FIA regulations such as to achieve the desired strength-to-weight ratio. (Federation International de l'Automobile 2022)
- It is also necessary to stick to a specific and tight budget allowing for the team to not surpass the cost cap implemented by Formula 1.
- Should undergo rigorous testing and validation for material properties, including tensile strength, fatigue resistance, and impact toughness.

2.5 Geometry and Dimensions

- Must meet dimensional specifications outlined in the team's design guidelines and CAD models.
- Should have adjustable mounting points to allow for fine-tuning of suspension geometry and alignment.

2.6 Manufacturing and Assembly

- Manufactured using advanced machining and fabrication techniques to ensure precise tolerances and consistent quality.
- Must be designed for ease of assembly and maintenance.

2.7 Testing and Validation

- Must undergo rigorous testing and validation procedures, including finite element analysis, physical testing, and on-track evaluation.
- Should simulate various operating conditions, including static loads, dynamic loads, and endurance testing, to ensure reliability and performance under race conditions.

2.8 Safety and Compliance

- Must comply with FIA regulations regarding suspension design and construction, including material specifications, dimensions, and performance criteria.
- Should have provisions for fail-safe features to prevent catastrophic failure and ensure driver safety in the event of component damage or failure.

2.9 Dependencies

- Dependent on input from aerodynamics team for integration with front wing and aerodynamic components.
- Collaboration with chassis design team for compatibility with chassis structure and mounting points.

Upper wishbone
(highlighted in yellow)



Figure 1 - Photograph of the front end of the 2023 Mercedes W14 including the wishbones

(<https://www.the-race.com/formula-1/gary-anderson-the-course-corrections-in-mercedes-f1-2023-design/>)

3 Material selection

Modern Formula 1 wishbones are typically constructed from advanced materials chosen for their combination of strength, stiffness, and lightweight properties.

- **Aerospace-Grade Aluminium Alloys:**

Aluminium alloys such as 7075 or 6061 are commonly used in Formula 1 due to their high strength-to-weight ratio. These alloys offer excellent machinability and can be tailored through heat treatment for improved mechanical properties.

- **Carbon Fibre Composites:**

Carbon fibre reinforced polymers (CFRP) are increasingly popular in Formula 1 for their exceptional stiffness and low weight. Carbon fibre composites offer high strength-to-weight ratio, excellent fatigue resistance, and can be moulded into complex shapes to optimize performance.

- **Titanium Alloys:**

Titanium alloys like Ti-6Al-4V offer a favourable strength-to-weight ratio and excellent corrosion resistance. While less common than aluminium or carbon fibre, titanium may be used in specific applications where high strength and durability are critical.

- **Magnesium Alloys:**

Magnesium alloys are known for their lightweight properties, making them attractive for weight-sensitive applications in Formula 1. However, magnesium alloys require careful design and manufacturing considerations due to their susceptibility to corrosion and fire hazards.

- **Hybrid Composites:**

Hybrid materials, combining different types of fibres or combining fibres with metallic elements, are also explored for their potential to achieve a balance between strength, stiffness, and weight savings.

Table 1 - Material properties

Materials	Tensile strength (MPa)	Tensile modulus (GPa)	Elongation (%)	Density (g/cm ³)	Strength-to-weight ratio (MPa/g/cm ³)
Aluminium alloy 6061	310	68.9	17	2.7	115
Carbon fibre	5407	264	1.75	1.79	3026
Titanium	620	113.8	14	4.43	140
Magnesium (cast)	280	45	25	1.74	486

(Total Materia 2002; Robin Francis 2019; Gernitix 2023)

These are various examples of possible materials that could be used to create the wishbones of F1 cars. The table above showing their different tensile strengths along with their percentage of elongation and various other measurements.

The choice of material depends on various factors, including performance requirements, design constraints, manufacturing considerations, and cost. Teams may conduct extensive testing and analysis to select the most suitable material for their specific application, considering factors such as stiffness, fatigue resistance, aerodynamic performance, and overall vehicle dynamics. Additionally, Formula 1 regulations may impose constraints on material choices to ensure safety and fairness among teams.

Carbon fibre being the chosen material by all teams with its very high strength to weight ratio.

4 Manufacturing process selection

Carbon fibre components in Formula 1 and other high-performance industries are typically manufactured using advanced composite manufacturing processes.

4.1 The different carbon fibre manufacturing processes

The following being some of the different manufacturing processes for carbon fibre components:

4.1.1 Prepreg Layup:

- Prepreg (pre-impregnated) carbon fibre sheets, which already contain the resin matrix, are laid up in the desired orientation and shape over a mould or tool.
- The layup may involve multiple layers, each oriented to optimize mechanical properties such as stiffness and strength.
- Vacuum bagging or autoclave curing is often used to consolidate the layup and ensure proper resin infusion and curing.

4.1.2 Resin Transfer Moulding (RTM):

- In RTM, dry carbon fibre fabric is placed in a mould cavity, and the mould is closed.
- Resin is then injected into the mould under pressure, impregnating the dry fibres and forming the composite part.
- RTM offers the advantage of producing parts with complex shapes and consistent fibre alignment, making it suitable for high-performance applications.

4.1.3 Autoclave Curing:

- Autoclave curing involves placing the laid-up carbon fibre components inside a sealed autoclave chamber.
- The autoclave applies heat and pressure to the component, allowing the resin to cure under controlled conditions.
- This process ensures thorough consolidation, void removal, and optimal mechanical properties in the final part.

4.1.4 Filament Winding:

- Filament winding involves winding continuous carbon fibre filaments around a rotating mandrel in a predetermined pattern.
- Resin is applied to the fibres during winding or post-winding to impregnate the fibres and form the composite structure.

- Filament winding is often used for producing cylindrical or tubular components such as suspension arms or roll hoops.

4.1.5 Compression Moulding:

- Compression moulding involves placing dry carbon fibre fabric or preforms in a mould cavity and applying heat and pressure to consolidate the material.

- The resin matrix is typically in the form of a film or resin powder, which melts and flows under pressure to impregnate the fibres.

- Compression moulding is suitable for producing parts with complex geometries and moderate production volumes.

4.1.6 Hand Layup:

- Hand layup involves manually laying up dry carbon fibre fabric or prepreg sheets onto a mould surface.

- Skilled workers use rollers and brushes to remove air and ensure proper fibre alignment.

- Hand layup is labour-intensive but offers flexibility and control over fibre orientation, making it suitable for prototyping and small production runs.

4.2 Best suited manufacturing process

Each of these manufacturing processes has its advantages and limitations, and the choice depends on factors such as part complexity, production volume, cost considerations, and required mechanical properties. Formula 1 teams often employ a combination of these processes to optimize the performance and production efficiency of carbon fibre components. RTM and autoclave processes are preferred for manufacturing wishbones due to their ability to accommodate complex shapes. Unlike cylindrical components, wishbones often feature intricate geometries, incorporating aerodynamic considerations. These processes are best suited for producing parts with such complexities, ensuring precise moulding and consolidation of the carbon fibre.

(Adam 1997; formlabs 2024)

5 Conclusion

Formula 1 is a very complex sport and industry with high costs and tight budgets, engineers are forced to innovate and adapt at a rapid rate all the while pushing the limits and constantly evolving the cars and technologies. When it comes to the suspension components these are a vital part of the car and must be able to withstand high forces ensuring the integrity of the chassis and the safety of the driver. These components are heavily regulated therefore narrowing down the available materials in which they can be fabricated.

In conclusion to the research and findings it is evident that carbon fibre is the optimal choice when designing and fabricating the wishbones of a Formula 1 car. This is proven with both its figures for tensile strength and modulus along with its strength to weight ratio being over 6 times greater than that of the nearest possible material, titanium.

After having proven the use of carbon fibre to be the best suited, research revealed several different methods of producing carbon fibre components. Each of these methods differ in costs, ease and production time required. Using advanced methods such as RTM and autoclave curing ensures the parts are consistent in design and meet the strength requirements stated by the regulations.

Moreover, these methods of production allow for the conception of more complex pieces allowing engineers to create both strong and aerodynamic efficient wishbones.

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