International Journal of Interdisciplinary Innovative Research &Development (IJIIRD)
ISSN: 2456-236X
Vol. 08 Issue 01 | 2023

Modelling and Comparative Analysis of Bicycle Frame Using CAE Tools with Engineering Materials

Krushnakant Prakash Sable[1], Prof. Amol M. Bhelkar[2]
[1,2] *Department of Mechanical Engineering, School of Engineering and Technology G H Raisoni University, Amravati*

ABSTRACT

A bicycle is a two wheeled vehicle that is moved with pedals, which are attached to the wheels with a gear and chain. It is steered with handlebars. A bicycle, also called a pedal cycle, bike or cycle, is a human-powered or motor-powered assisted, pedal- driven, single- track vehicle, having two wheels attached to a frame, one behind the other. A bicycle rider is called a cyclist, or bicyclist.

Bicycles were introduced in the 19th century in Europe. By the early 21st century, more than 1 billion were in existence. These numbers far exceed the number of cars, both in total and ranked by the number of individual models produced. They are the principal means of transportation in many regions. They also provide a popular form of recreation, and have been adapted for use as children's toys, general fitness, military and police applications, courier services, bicycle racing, and bicycle stunts. The basic shape and configuration of a typical upright or "safety bicycle", has changed little since the first chain-driven model was developed around 1885. However, many details have been improved, especially since the advent of modern materials and computer-aided design. These have allowed for a proliferation of specialized designs for many types of cycling.

Keywords: CAE Tools, Bicycle Frame, Ansys.

1. INTRODUCTION

The bicycle's invention has had an enormous effect on society, both in terms ofculture and of advancing modern industrial methods. Several components that played akey role in the development of the automobile were initially invented for use in the bicycle, including ball bearings, pneumatic tires, chain-driven sprockets and tensionspoked wheels.

Although bike and cycle are used interchangeably to refer mostly to two types of two-wheelers, the terms still vary across the world. In India, for example, a cycle refers only to a two-wheeler using pedal power whereas the term bike is used to describea two-wheeler using internal combustion engine or electric motors as a source of motivepower instead of motorcycle/motorbike.

In the early 1860s, Frenchmen Pierre Michaux and Pierre Lallement took bicycle design in a new direction by adding a mechanical crank drive with pedals on anenlarged front wheel (the velocipede). This was the first in mass production. Another French inventor named Douglas Grasso had a failed prototype of Pierre Lallement's bicycle several years earlier. Several inventions followed using rear-wheel drive, the best known being the rod- driven velocipede by Scotsman Thomas McCall in 1869. Inthat same year, bicycle wheels with wire spokes were patented by Eugene Meyer of Paris. The French velocipede, made of iron and wood, developed into the "pennyfarthing" (historically known as an "ordinary bicycle", a retronym, since there was then no other kind). It featured a tubular steel frame on which were mounted wire-spoked wheels with solid rubber tires. These bicycles were difficult to ride due to theirhigh seat and poor weight distribution.

Bicycles can be categorized in many different ways: by function, by number of riders, by general construction, by gearing or by means of propulsion. The more common types include utility bicycles, mountain bicycles, racing bicycles, touring bicycles, hybrid bicycles, cruiser bicycles, and BMX bikes. Less common are tandems,low riders, tall bikes, fixed gear, folding models, amphibious bicycles, cargo bikes, recumbents and electric bicycles.

A bicycle stays upright while moving forward by being steered so as to keep itscenter of mass over the wheels. This steering is usually provided by the rider, but undercertain conditions may be provided by the bicycle itself.The combined center of mass of a bicycle and its rider must lean into a turn tosuccessfully navigate it. This lean is induced by a method known as counter steering,which can be performed by the rider turning the handlebars directly with the hands or indirectly by leaning the bicycle.

Short-wheelbase or tall bicycles, when braking, can generate enough stopping force at the front wheel to flip longitudinally. The act of purposefully using this force to lift the rear wheel and balance on the front without tipping over is a trick known as a stop pie, endo, or front wheelie.

2. LITERATURE REVIEW

Before going with the project, a brief study on papers related to Design And StructuralAnalysis of A Bicycle Frame Under Static Loading Conditions was done. Many authorsportrayed different ideas related to their works on the design of bicycle frames and analysis on different frames. The different papers reviewed are listed below:

Vignesh.M et al 2019 modelled optimum design for an electric bike and analyzed for stress and failure rate for commercial purpose. The main objective was to design and fabricate a light weight still strong, safe, and economical than the conventional ones.

Derek Civil et al proposed use of a finite element model to simulate the behavior for astandard steel bicycle frames under a range of measured load cases. These load cases include those measured both in the laboratory setting and also in the field, and includeloads transmitted at key areas such as the dropouts and hub, the bottom bracket and drive, the headset and handlebars, and the seat post and saddle.

W H Tan et al 2021 studied that how the changing of material of the bicycle frame andthe insertion of the suspension system can reduce vibration. This study was conductedusing Aluminium alloy as the material for bicycle frame to reduce the vibration and the weight of the bike. The suspension system has also been customized into the bicycle frame as the main vibration absorber. The CAD model was developed and been analysed using static and dynamic analysis based on the specific boundary condition.

Zhang Long et al 2015 found the best position of human-bike system, simulation experiments. On riding comfort under different riding postures are done with the life mode software employed to facilitate the cycling process as well as to obtain the best position and the size function of it. With BP neural network and GA, analysing simulation data, conducting regression analysis of parameters on different heights andbike frames, the equation of best position of human-bike system is gained at last.

Y. Champoux et al 2004 optimized their choice of geometry and tube thickness, bicycleframe manufactures need to use an approach for a modern design on a finiteelement model. They presented new measurement techniques and an overview of the different approaches. Knowledge about the loads carried by off-road bicycles provides crucial information to bicycle frame manufacturers, allowing them to develop and propose newand optimized versions of their product.

Arun Abishek.T et al 2021 analysed the single main frame electric bike chassis usingmaterial AISI 1018 low carbon steel. The Design and Analysis of Single Main Frame Electric Bike Chassis was done successfully by using Ansys workbench software. Fromthe Ansys workbench Total Deformation, Equivalent Shear stress, Maximum Shear Stress, Equivalent Shear Strain, Maximum Shear Strain are obtained. The material AISI-1018 Low carbon steel gives positive results.

Krishan Kumar Mishra et al 2021 designed bicycle frame which is done in solid works and is analysed in Ansys software. The frame is imported into Ansys and the analysis is done which includes Stress, Strain and Total deformation of some conditionare analysed. Conditions of analysis are static, rear wheel braking, steady state pedalling, vertical impact, horizontal impact.

Nair Ajit et al 2018 replaced bicycle frame material with magnesium alloy (AZ91D) and performed the analysis such as FEM, structural, static analysis, dynamic analysis and report the deformation under different loading conditions, and ensured the implementation of modified mountain bike frame with magnesium AZ91D alloy. The bicycle frame is designed by using CREO PARAMETRIC 3.0 and the analysis of the bicycle frame is done by using ANSYS software tool. A modified mountain bike framemodel was created to simulate the behaviour of the frame under a range of measured load cases.

3. METHODOLOGY

Here's a detailed methodology for designing and analyzing a bicycle frame using Creoand ANSYS:

Define design requirements: Determine the specific requirements for the bicycle frame, such as desired material, weight, stiffness, and performance criteria.

Conceptual design: Sketch different frame designs considering factors like frame geometry, tubeshapes, and connection points. Evaluate each concept based on the design requirements and select the mostpromising one to proceed.

Detailed design in Creo: Create a detailed 3D model of the selected frame design in Creo or any otherCAD software. Ensure accurate dimensions, tube thickness, and appropriate connections between tubes and components.

Export the model: Export the 3D model from Creo in a format compatible with ANSYS, such as STEPor IGES.

Import the model into ANSYS: Open ANSYS and import the exported model. Verify that the model imports correctly and that all components are intact.

Preprocessing in ANSYS: Clean up the imported geometry, ensuring that there are no gaps or overlappingsurfaces. Verify the scale and units of the model to ensure consistency with the analysisrequirements.

Mesh generation: Generate a suitable mesh to discretize the geometry into smaller elements. Choose an appropriate element type and mesh density for accurate analysis results. Ensure that the mesh is refined in critical areas where

high stress or deformation isexpected.
Material assignment: Assign material properties to different parts of the bicycle frame in ANSYS. - Define the material type, density, Young's modulus, Poisson's ratio, and any other relevant properties.
Apply loads and constraints: Define the boundary conditions for the analysis to represent real-world scenarios. - Apply loads that mimic the forces experienced during cycling, such as rider weight, pedaling forces, and external forces like bumps. Apply constraints to simulate the bike's connection to the ground or other components.
Analysis setup: Configure the analysis settings in ANSYS, such as selecting the appropriate solvertype and defining convergence criteria. Specify other relevant analysis parameters, such as the type of analysis (static, dynamic, or fatigue), time duration (if applicable), and solution control options.
Perform the analysis: Run the analysis in ANSYS to calculate the structural behavior of the bicycle frameunder the applied loads and constraints. Monitor the progress and convergence of the analysis, ensuring that it completessuccessfully.
Postprocessing and result interpretation: Analyze the results obtained from ANSYS, including stress distribution, deformation,and factor of safety. Identify areas of high stress concentrations, deformations, or any other anomalies thatmay require design refinement. Compare the results against the design requirements to assess the frame's performance. Visualize and interpret the results using ANSYS postprocessing tools.Design refinement: If analysis results reveal any issues or deviations from design requirements, iterate onthe design. Make necessary adjustments to the frame geometry, material selection, or otherparameters based on the analysis findings. Repeat the analysis and interpretation steps until the design meets all the requiredcriteria.
Throughout the process, it's crucial to refer to relevant industry standards, safety guidelines, and any specific regulations that govern bicycle frame design. Regularly communicate with experts or seek feedback from experienced individuals in the field to ensure the design meets the necessary standards and safety considerations.

4. DESIGN AND ANALYSIS

Design of frame

The body of the bicycle is designed using tools such as sketch tools as of line, circle, spline, arc in different planes. The features tools in the creo were used to get the 3- dimensional or the body such as boss extrude, extrude cut and many other features.
Some of the important tools and commands used in the design of the bicycle are:

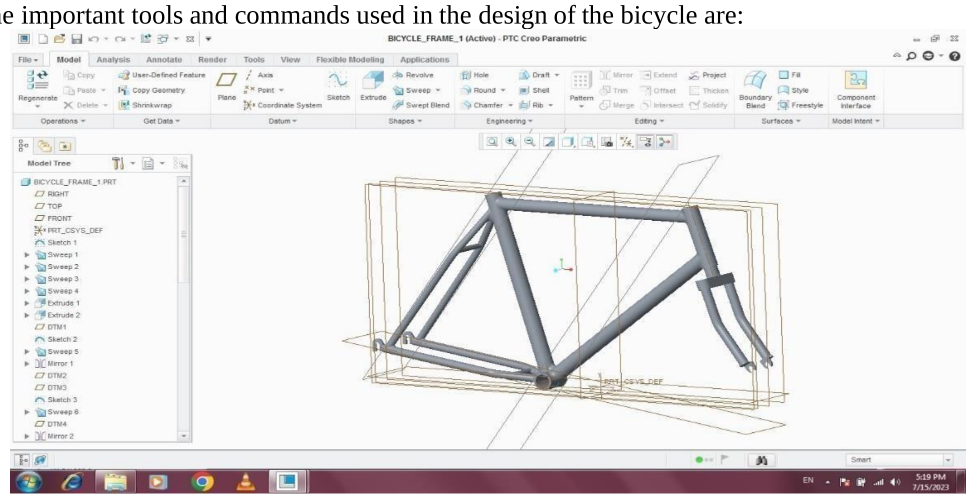


Fig 1. Creo interface

Creo Parametric Modelling Procedure

- Open PTC Creo Parametric 7.0
- Click on 'Select Working Directory' button in Home Menu to assign aDestination folder in
- any specific drive of the computer so that the work will be saved.
Click on 'New' button in Home Menu, will open a small window which shows variousTypes
- & Sub Types of Modeling Work.
- Select 'Part' as a Type & 'Solid' as Sub Type, Edit 'Name' of the part.
- Deselect the right tick in 'Use Default Template' dialogue box of & click'OK'
- Select 'mmns_part_solid' in New File Option and click 'OK', will openthe working
- environment of Creo Parametric.
- Select a 'Datum Plane' (Right / Top / Front) for reference & click on'Sketch' for sketching
- on flat reference.

- Click on 'Sketch View Button' to orient the sketching plane parallel tothe screen.
- Start Sketching / Drafting using various commands like 'Line', 'Circle','Rectangle', 'Arc',
- 'Eclipse', 'Spline' etc.
- Click 'OK' after completing the required 2D Drafting.
- Click 'Extrude' in Model menu to create Three Dimensional Geometryby projecting a two
- dimensional section at a specified distance normal to the sketching plane.
- Bicycle Frame is built with Round Section Pipes, so we make it usingSWEEP or SWEEP
- BLEND in Creo Parametric.
- For 'Sweep' or 'Sweep Blend', a two dimensional sketch is sketch in anydatum plane, click
- OK to back in Modeling Menu.
- Select the 2D sketch, click on 'Sweep', click on 'Sketch Section Button'to Create or Edit the
- Sweep Section.
- Click on the 'Sketch View Button' to orient the sketching plane parallelto the screen.
- Sketch on the reference section as required & click 'OK'.
- For reference datum plane Click on 'Plane', Select the Reference plane,select Reference
- Edge or Surface, Apply the Required Angle.
- For mirroring the geometry click on the 'Mirror' option, select thegeometry to mirror, then
- select the reference plane, click 'OK'.
- To save the work, Go to file menu, click 'Save as' then 'Save a copy' tosave the copy of the
- object in the active window.

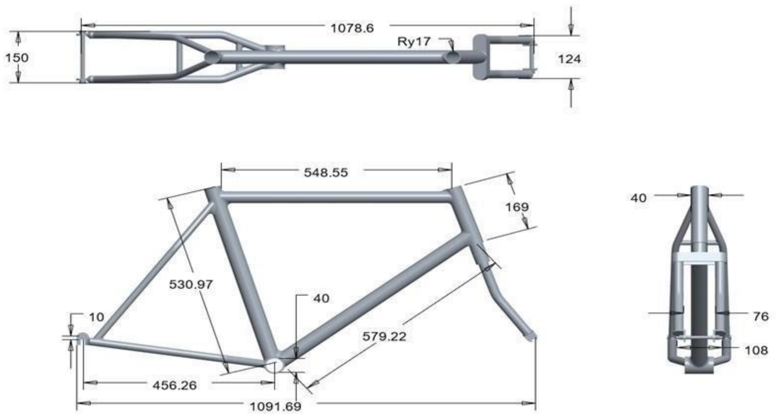


Fig. 2 Dimensions of the frame

ANALYSIS

An analysis model defines a coherent set of required properties of the systemunder development. Many of the design criteria are the quality of service constraints from the analysis. There may be others as well, such as reliability and safety level,reusability, maintainability, simplicity, time to market, and so on. Design analysis isthe systematic process of developing a design including all information discovery, planning and communications. This can be applied to any type of design includingthe design of physical things such as buildings and intangible things such as software, information and process.

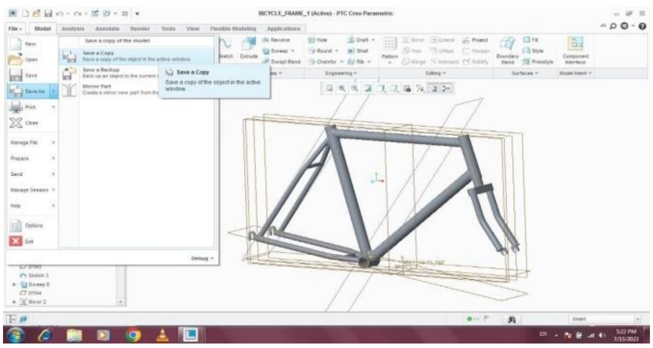


Fig 3 Creo to Ansys

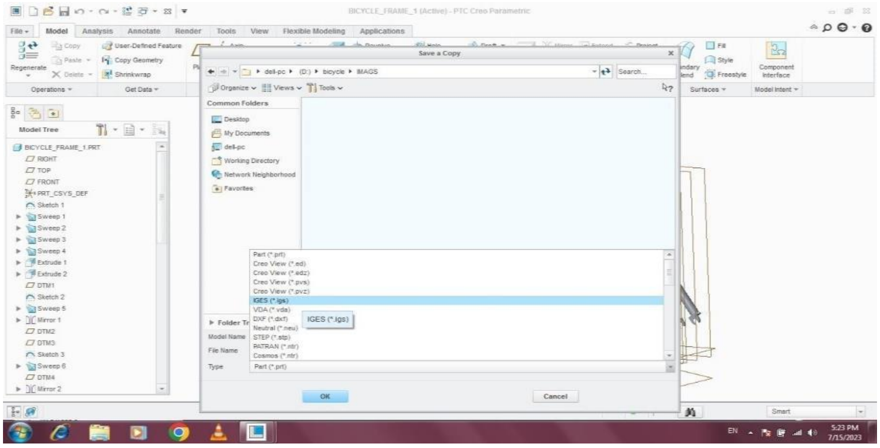
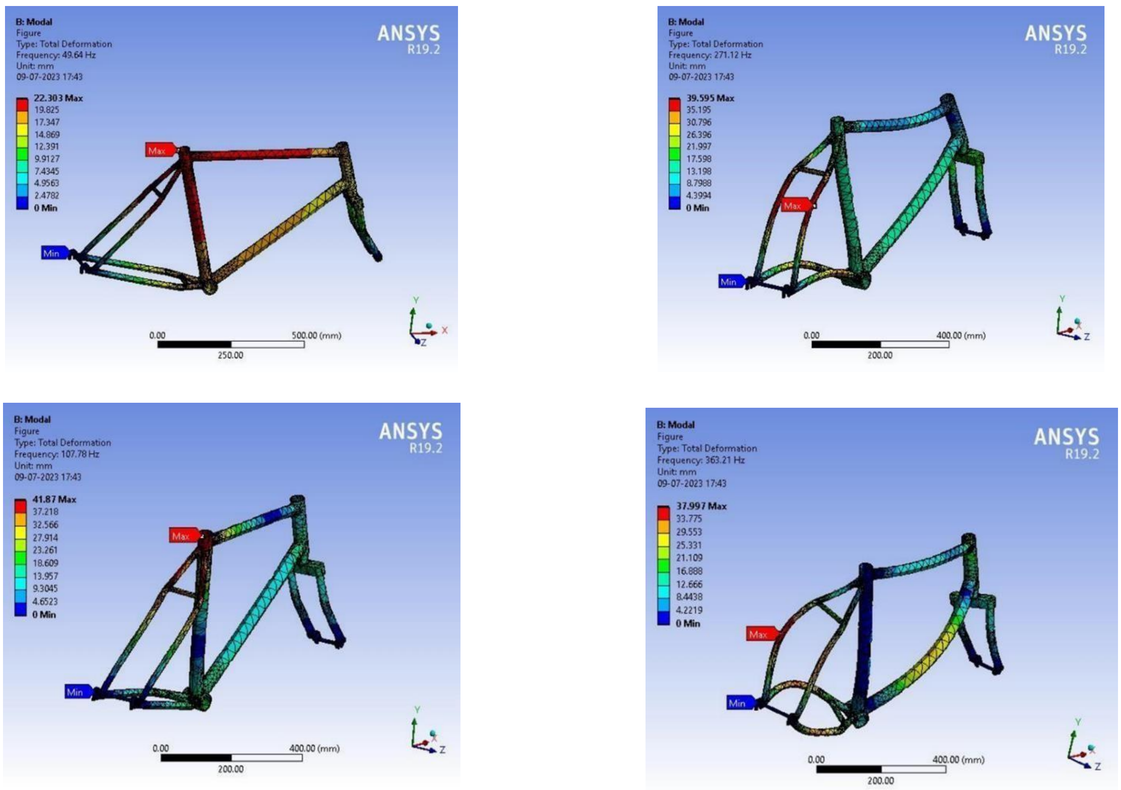


Fig 4 Creo to Ansys

5. MODAL ANALYSIS

Table .1

Mode	Frequency [Hz]
1.	49.64
2.	83.757
3.	107.78
4.	271.12
5.	320.79
6.	328.47
7.	363.21
8.	367.61
9.	395.4
10.	428.33



Figs of 5. Total Deformation

Static Structural Results

Type	Total Deformation	Directional Deformation	Equivalent (vonMises) Stress	Maximum Principal Stress	Equivalent Elastic Strain	Maximum Principal Elastic Strain	Maximum Shear Stress
Results							
Minimum	0. mm	-0.24411 mm	1.838e-008 MPa	-17.509 MPa	1.6827e-012 mm/mm	-3.0559e-006 mm/mm	9.1934e-009 MPa
Maximum	0.38731 mm	0.23682 mm	173.85 MPa	131.25 MPa	1.5741e-003 mm/mm	1.0481e-003 mm/mm	91.923 MPa
Average	0.25213 mm	1.202e-002 mm	9.0716 MPa	2.9371 MPa	1.4148e-004 mm/mm	7.1495e-005 mm/mm	4.8296 MPa
Minimum Occurs On	Bicycle_Frame_FinalFreeParts	Bicycle_Frame_FinalFreeParts[3]	Bicycle_Frame_Final-FreeParts			Bicycle_Frame_FinalFreeParts[3]	Bicycle_Frame_FinalFreeParts
Maximum Occurs On	Bicycle_Frame_Final-FreeParts[3]		Bicycle_Frame_Final-FreeParts	Bicycle_Frame_Final-FreeParts[3]			Bicycle_Frame_FinalFreeParts

Table 2

Modal solution

Object Name	*Total Deformation*	*Total Deformation 2*	*Total Deformation 3*	*Total Deformation 4*	*Total Deformation 5*	*Total Deformation 6*	*Total Deformation 7*	*Total Deformation 8*	*Total Deformation 9*	*Total Deformation 10*
Results										
Minimum	0. mm									
Maximum	22.303 mm	34.287 mm	41.87 mm	39.595 mm	34.847 mm	44.012 mm	37.997 mm	33.88 mm	57.616 mm	77.486 mm
Average	14.493 mm	13.19 mm	17.15 mm	15.881 mm	11.567 mm	11.581 mm	11.825 mm	7.6962 mm	13.206 mm	12.844 mm
Minimum Occurs On	Bicycle_Frame_Final-FreeParts									
Maximum Occurs On	Bicycle_Frame_Final-FreeParts[3]									
Information										
Frequency	49.64 Hz	83.757 Hz	107.78 Hz	271.12 Hz	320.79 Hz	328.47 Hz	363.21 Hz	367.61 Hz	395.4 Hz	428.33 Hz

Table 3

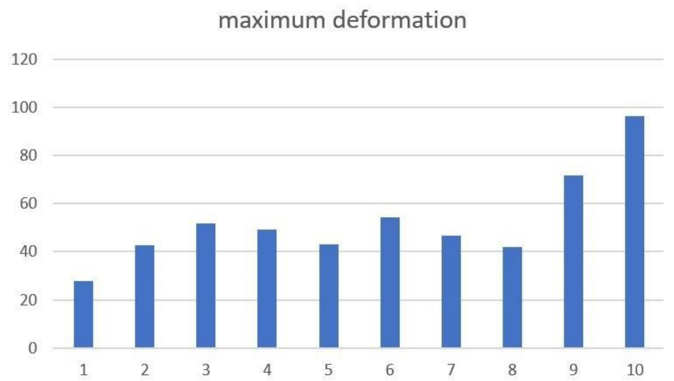


Fig 6 Graphical representation of deformation in material

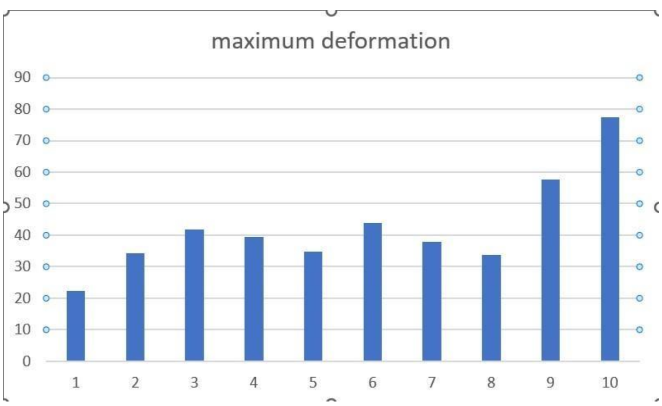


Fig. 7 maximum deformation in magnesium alloy

6. CONCLUSION AND FUTURE SCOPE

CONCLUSION

Aluminium and magnesium are two commonly used materials for bicycle frames, and they exhibit several differences in their structural properties. Here are somekey differences between aluminium and magnesium bicycle frame structures:

Weight: Magnesium is lighter than aluminium, which makes magnesium frames attractive for riders looking to reduce the overall weight of their bicycles. A lighter frame can contribute to improved acceleration and climbing ability. However, it's important to note that other factors, such as frame design and construction, also impactthe overall weight of the bicycle

Stiffness: Aluminium frames are generally stiffer than magnesium frames. Stiffness refers to a material's resistance to bending or flexing. The higher stiffness of aluminium frames can provide better power transfer and responsiveness, resulting in a more efficient ride. Magnesium frames, while lighter, may have slightly more flex or compliance, which can provide a smoother and more comfortable ride.

Strength: Aluminium is known for its strength and durability, making it a reliable choice for bicycle frames. It has a high strength-to-weight ratio, meaning it can withstand significant loads while remaining relatively lightweight. Magnesium is notas strong as aluminium, and therefore, magnesium frames may require additional reinforcement or thicker sections to achieve the desired strength. Proper design and manufacturing techniques are crucial to ensure the structural integrity of magnesium frames.

Fatigue Resistance: Aluminium frames generally exhibit good fatigue resistance, meaning they can withstand repeated stress cycles without failure. Magnesium frames,on the other hand, may be more susceptible to fatigue and cracking over time. This isdue to the lower fatigue strength of magnesium compared to aluminium. However, advancements in magnesium alloy formulations and manufacturing processes can improve the fatigue resistance of magnesium frames.

Corrosion Resistance: Aluminium has inherent corrosion resistance, forming a protective oxide layer that helps prevent rust and corrosion. Magnesium, on the otherhand, is more prone to corrosion, especially in harsh environments or if not properlyprotected. Surface treatments and coatings can be applied to magnesium frames to enhance their corrosion resistance

Scope

The future of bicycle frames is likely to see several advancements and developments astechnology and materials continue to evolve. Here are some potential areas of future scope in bicycle frame design and technology:

Lightweight Materials: Manufacturers will continue to explore new lightweightmaterials or combinations of materials to further reduce the weight of bicycle frames. This could involve advancements in carbon fiber composites, metal alloys, or the integration of nanomaterials to enhance strength-to-weight ratios.

Advanced Composites: The use of advanced composites, such as graphene or other high-performance fibers, may become more prevalent in bicycle frame construction. These materials offer exceptional strength, stiffness, and durability, which can lead to even lighter and stronger frames.

Smart Materials: Integration of smart materials into bicycle frames could enhance performance and functionality. For example, materials with shape memory alloys couldprovide adaptive properties, allowing the frame to adjust its shape or absorb vibrationsbased on road conditions or rider input.

Additive Manufacturing: 3D printing or additive manufacturing techniques have thepotential to revolutionize bicycle frame production. It allows for complex geometries,customization, and lightweight lattice structures that were previously challenging to achieve. As additive manufacturing technology advances, we may see more optimizedand personalized bicycle frames.

Sustainable Materials: With increasing focus on sustainability, there is potential for thedevelopment of more environmentally friendly materials for bicycle frames. This could
involve bio-based polymers, recycled composites, or natural fibers. The goal would beto reduce the environmental impact of frame production and end-of-life disposal.

Aerodynamics: As cycling performance gains importance, future bicycle frames may feature improved aerodynamic designs. Frames could be optimized for reduced drag and improved airflow, leading to increased speed and efficiency.

Integrated Technologies: Integration of various technologies within the frame itself could become more prevalent. This could include integrated sensors for performance monitoring, power meters, wireless charging capabilities, or even energy-harvesting technologies to power electronic components on the bike.

Customization and Personalization: Advances in manufacturing techniques, such asrobotic automation or AI-assisted design, could enable greater customization and personalization options for bicycle frames. Riders may be able to specify frame geometries, stiffness characteristics, or even have frames tailored to their body measurements.

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