Research Paper

Material selection and optimization of torsion bar suspension for military vehicle in case of tank T-55

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ABSTRACT

This project focuses on the analyzing different materials for torsion bar suspension system for Tank T-55 for optimizing its performance for cross country mobility and ride comfort. This suspension system is aimed to improve wheel travel and angle of twist on all terrain conditions from rough to flat surfaces. The different materials studied are carbon steel and alloy steel for their suitability as torsion bar and proposed de-sign is accomplished through the material selection and analytical calculation with analysis for shear stress, total deformation and strain. Alloy steel is considered as alternative material for torsion bar based on the result of its good strength in shear stress and store maximum energy in the case of strain energy.

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1. INTRODUCTION

The ride characteristics and maximum achievable speed over rough ground of tanks largely depends on the extent to which their suspension can absorb the irregularities of the ground sur-face. Many main battle tanks from different nations, such as the United States, Germany, France, Britain, and Japan, use torsion bar suspension systems. Russian-made armored fighting vehicles are all equipped with torsion bar suspension. The primary factors contributing to the extensive usage of torsion bar suspension are its low weight, excellent performance, and ease of manufacture. In early days the wheel travel was comparatively less, but due to advancement in material technology, present day torsion bars have allowed higher stresses to be imposed on the bars, thereby greater degrees of twist and more wheel travel for any given length of bar. Early designs of torsion bars had only 130mm wheel travel. With improved materials like ESR steel the wheel travel now reached up to 385mm in USA, M-1 ABRAHMS. Russian tank T-55 which uses torsion bar suspension has a wheel travel of only 218 mm which is very low. In order to ensure the comfort of passengers and the evenness of vehicle operation, most of the vehicles use the easier two-system suspended suspension system [1].

A thin steel tube known as a torsion bar is fastened to the vehicle's control arms and twists along its length, or axis, when the control arm moves up and down. The other end is secured in place and does not twist because it is attached to the vehicle's chassis. Tension is created when a wheel bumps and rises upward, causing the bar to twist out of the face. Following the impact, the steel bar softens and forces the wheel to descend once more. This results in ride discomfort, issues with ride safety, and dynamic straining of the vehicle's frame [2]. All serial main battle tanks built in the US, Germany, and Russia (the former Soviet Union), as well as one kind of French main battle tank, one Japanese main battle tank, and certain British tanks intended for export, had Torsion bar suspension systems installed. For military and au-to mobile vehicles to be handled safely and to ride comfortably, torsion bars are essential. Torsion bars are more suitable for supporting large loads than coil springs. Coil springs distribute the weight of the vehicle more uniformly across a smaller surface area of the chassis, whereas torsion bars do the opposite. Drive axles and other suspension components can be placed in locations where other types of springs would be in the way because torsion bars are incredibly space-efficient and take up significantly less volume overall. Additional benefits of a torsion bar suspension are its modest profile across the width of the car, quick ride height adjustment, and durability. It requires less space inside the car than a coil spring [3].

2. RELATED WORK

A model is constructed for the dynamic dependability of mechanical components under the random load occurring on the torsion bar suspension system after the differences in strength, load, and reliability of mechanical components are explored with respect to time [4]. The armed army currently purchases T-55 tanks from overseas on a regular basis. This allows the troops to meet their requirement for high mobility, which is achieved by increasing wheel travel. This research de-scribes how torsion bars made of carbon fiber reinforced polymers (CFRP) outperform those made of steel through simplified early stress analysis [5]. Torsion deflections and energy storage of the composite bar in the torsion bar suspension system are examined, and solid steel bars were produced by thread winding and machined, then wounded with E-glass or epoxy [5].

This system is expected to improve vehicle performance on all land conditions from rough to flat surfaces. This paper offers fundamental knowledge of torsion investigation and important parameters such as torque, modulus of resilience in torsion and angle of twist has been underlined. The torsion deflections were obtained experimentally [6]. The major necessities of a Main battle tank (MBT) or a Combat vehicle (CV) is that it has to be mobile, has adequate protection and it needs the required firepower for each condition. The vehicle's movement is greatly influenced by the suspension system. A vehicle can travel over rough terrain more quickly and with less impact on the occupants when it has a robust suspension system [7]. Torsion bars are more familiar in the field of suspension systems made of mild steel and they were used in com-pact/limited spaces [8]. The privies work included failure evaluations and summaries of suspension coil springs. As a result, representative case finite element analyses were also modeled. The power of failure analysis is synergized into significant quantitative analysis by the integration of finite element modeling in metallurgical failure analysis. This is most likely going to be the failure analysis trend [9].

Constraints like the suspension's static deflection and range of motion with relation to the original suspension based on torsion bars have also been determined using the elastic spring model as a foundation.

Furthermore, internal stresses associated with spring deflection phases have been included these are essential for the spring's strength analysis. The distinctive design of the so-called hyperbolic spring is what makes the solution presented novel [10]. For high-mobility tracked vehicles, a spatial motion analysis model was developed to estimate ride quality, steering capability, and stability over uneven terrain [11]. Regular high- mobility tracked vehicles are equipped with independent torsion bar type suspension system, which consists of road arms and road wheels [12].

The suspension system of a car serves to both isolate the vehicle from the unpleasant vibrations that are transferred from the road through the tires and to return control forces to the tires, letting the driver to maintain control of the vehicle [13]. For off-road vehicles, the torsional bar in the driver's seat is crucial to the comfort of the operator. Torsional bars are often designed to absorb impact load in addition to shock. A special type of torsion bar is what is being planned in order to decrease vibration on the driver's seat. A mechanism was employed in a stepped bar with a control arm, and the bar's stiffness could be adjusted to absorb loads spread to the driver's seat Analyses the shearing stress distribution, deflection, stiffness and dimensions for proposed stepped bar by using ANSYS and compared the results with numerical result achieved [14]. Torsion bar springs are dynamically loaded machine elements which can break due to fatigue [15]. Given varying elastic plastic presetting torques, a torsion bar spring may exhibit varying fatigue behavior. The fatigue lifetime is strongly dependent on the ratio between the applied fatigue loading range and the preset elastic-plastic torque, according to experimental results. With one stationary end fastened to the car's frame and one rotating end fastened to the control arm, torsion bars function as a linear spring [16]. This kind of spring produces torques to overcome the vehicle's load force. An analytical study is directed to investigate the stress values of the composite torsion bar suspension system. A round solid composite bar is selected. The analysis was done on an ANSYS, a program designed specially to look at the static properties of the torsion bars used in car suspension systems. The study's findings may lead to the development of a more effective light-weight torsion suspension system [17].

In all the above project papers, the wheel travel of suspension system did not consider well. So, they have limitation on the improvement of the wheel travel. The other limitation within the above designers is that, they did not consider alternate materials and optimize the best material for military vehicle torsion bar suspension. So this thesis is focus on improve the wheel travel of torsion bar by using alternative materials after simulation analysis.

3. METHODOLOGY

3.1 Materials

Different materials as per their strength, can be manufactured to torsion bar suspension system. Among materials can be used in torsion bar design, the most three materials are selected to design and analysis suspension for its wheel travel and mobility as well. Carbon Steels, Alloy Steels and Stainless Steels properties are discussed. Based on physical properties and strength of the materials from material properties specification, alloy steel and carbon steel are the most strength materials and simulation is based on these two materials and used in modeling and analysis.

The torsion bar used in tank T-55 is designed with existing diameter and length for load analysis and optimizing with better material. T-55 tank torsion bar is manufactured using 52mm and 1930mm effective length with nominal steel. This thesis uses medium carbon steel and alloy steel for optimization. Solid work software is generally used in finite element investigation, but its pre-process function is so complex that one must have to devote too much time and energy, especially for complex model. In this project, the work is carried out by using SOLIDWORK for modeling and analysis. The comprehensive application of various finite elements software can exert their corresponding advantages and makes the analysis more efficient.

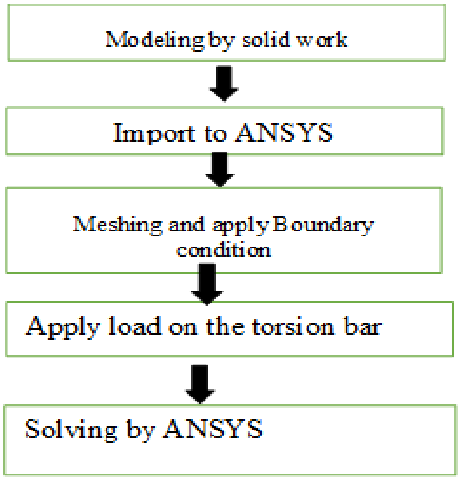


Figure 1. Flow Chart of ANSYS Analysis

The methods of modeling and simulation analysis is shown by Figure 1 above.

3.2 Data Collection

Existing torsion bar, length and diameter of the torsion bar of tank T-55 which used for analytical calculation is a measurement value of design and a data collected from the (Rade Stevanovic, BSc Characteristics of torsion bar suspension springiness in MBTs and the assessment of realized solutions.

3.3 The Existing Torsion Bar Parameters Are

Total length=2180mm
Effective length=1930mm
Diameter =52mm
Total wheel travel=218mm
Dynamic twist angle=50degree

Figure 2. Existing Torsion Bar of Tank T-55

Table 1. Specification of Torsion bar Tank T-55 and Data Used

No.	Parameters	Symbol	Values	Units
1	Weight of tank(static load)	W	36700	Kg
2	Effective length of torsion bar	L	1930	mm
3	Diameter of torsion bar	D	52	mm
4	Sprung mass	m_o	32950	Kg
5	Number of torsion bars	N	10	-
6	Clearance angle	φ_s	15.6	Degree
7	Arm length	A	250	Mm
8	Acceleration due to gravity	G	9.81	m/s^2
9	Area moment of	I	3.589e00-7	m^4
10	Polar moment of area	J	7.178e00-7	m^4

As shown in Table 1 above, data are collected from T-55 specification and the other length dimensions are measured by meter and data used as input for ANSYS simulation.

3.4 Modeling of Torsion Bar Suspension

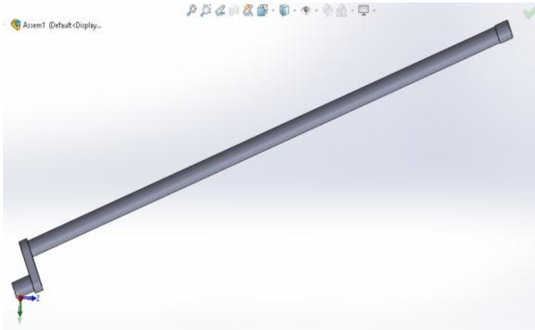


Figure 3. Solid Work Modeling Torsion Bar

3.5 Numerical Calculation

3.5.1 Torque Calculation

Torque is the twisting force that tends to cause rotation. The point where the object rotates is known as the axis of rotation. Mathematically, torque can be written as

$$T = F \times r \times sin\theta ------(1)$$

F=W; W is dynamic load which is twice of static load of the tank.

Static load of tank t-55=36700kg;

$$W = 2 \times staticload \times g ----- (2)$$

3.5.2 Moment Calculation

It is the rotating effect produced by a force, on the body, on which it acts. The moment of a force is equivalent to the product of the force and the perpendicular distance of the point, about which the moment is required, and the line of action of the force.

Mathematically

$$M = F_s \times \ l --------(3)$$

Where $F_s = m_o \times g$

Table 2. Properties of Materials and Data Used for Torsion bar Calculation

No:	Parameters	Symbol	Values		Unit
			Steel	Alloy Steel	
1	Shear modulus	G	85	4	Gpa
2	Young modulus	E	200	2.93	Gpa
3	Nominal shear stress heat treatment	τ_d	1250	70	Mpa
4	Ultimate yield strength	σ_y	4.723	0.103	Gpa
5	Maximum shear stress at yield limit	τ_y	2.36	0.0515	Gpa

3.5.3 Torsion Bar Spring Rate

A torsion spring is a spring that works by torsion or twisting; that is, a flexible elastic object that stores mechanical energy when it is twisted. Torsion bar spring rate can be calculated from the ratio of Torque of torsion bar and twist angle, and mathematically it will be

$$C = \frac{\pi G d^4}{32L} ----------- (4)$$

Since, C=T/ θ

$$\theta = \frac{32TL}{\pi G d^4}$$

Torsion bar twist angle in static wheel position.

A moment of torque causes a structure to twist. A torque allocates tension over the object's cross section as opposed to axial loads, which causes a uniform or average stress to be generated. In the interest of simplicity, the study will concentrate on constructions that have a circular cross section, occasionally referred to as rods or shafts. The structure will twist along the rod's long axis when a torque is applied, but its cross section will stay circular.

$$\theta_s = \left(\frac{a}{g}\omega_z^2 \cos\varphi_s + \tan\varphi_s\right)^{-1} --(5)$$

Where $\omega_z = 2\pi v_z = \sqrt{\frac{C_{rs}}{m_o/N}}$ and $C_{rs} = \frac{C(1-\theta_s \tan\varphi_s)}{(a\cos\varphi_s)^2}$

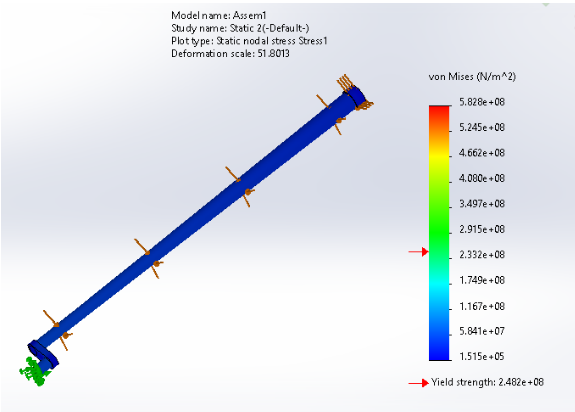
3.5.4 Total wheel Travel of Suspension

Wheel rate is the spring rate of a theoretical spring close directly above the wheel. Identical to spring rate, wheel rate is measured in lbs/in. To keep our measurements consistent, we make a few assumptions in our calculations.

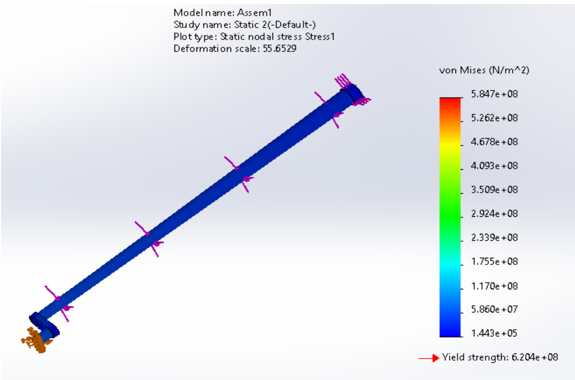
$$f_m = f_d + f_{st} -------(6)$$

4. RESULTS AND DISCUSSION

4.1 Maximum Shear Stress



(A) Maximum Shear Stress of Medium Carbon Steel Torsion Bar



(B) Maximum Shear Stress of Alloy Steel Torsion Bar

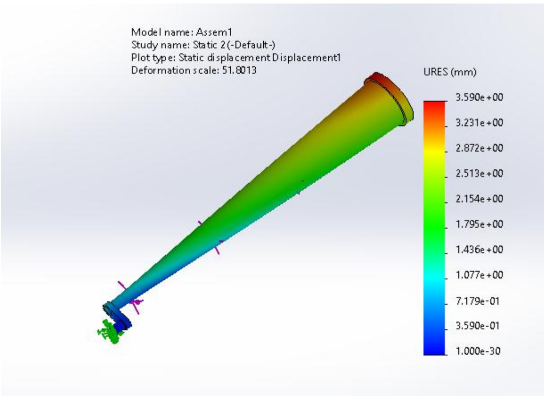
Figure 4. Maximum Shear Stress Analysis

Figure 5 and Table 3 below carbon steel and alloy steel materials are studied under solid work simulation and the Shear stress in case of carbon steel is less than that of alloy steel material. However, maximum shear stress in carbon steel is not enough greater than the yield stress which shows that the design is not safe. But, in case of alloy steal the yield strength is enough maximum than maximum shear stress, so design is safe.

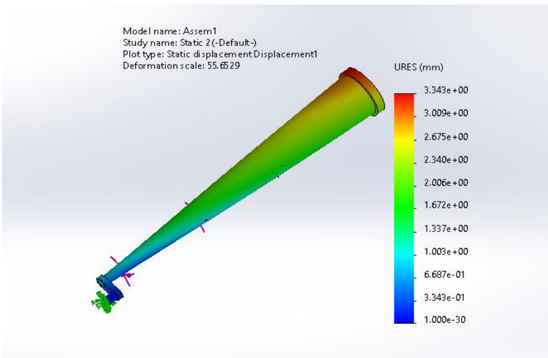
Table 3. Comparison of Shear Stress with Analytical Calculation

No.	Materials	Shear Stress Values	Unit	No
1	Carbon steel	Maximum value	5.828×10^{8}	N/m^2
		Minimum value	1.515×10^{5}	N/m^2
		Theoretical calculation	1.248×10^{9}	N/m^2
		Yield shear stress	2.482×10^{8}	N/m^2
2	Alloy steel	Maximum value	5.847×10^{8}	N/m^2
		Minimum value	1.443×10^{5}	N/m^2
		Theoretical calculation	6.8×10^{7}	N/m^2
		Yield shear stress	6.204×10^{8}	N/m^2

4.2 Total Deformation



(A) Alloy Steel Torsion Bar Under Deformation



(B) Torsion Bar of Carbon Steel Under Deformation

Figure 5. Total Deformation Analyses

Table 4. Comparison of Total Deformation with Calculation

No	Materials		Deformation Values	Unit
1	Alloy steel	Maximum value	0.003343	m
		Minimum value	0	m
		FOS		

2	Carbon Steel	Maximum value	0.00359	m
		Minimum value	0	m
		FOS	1.1	

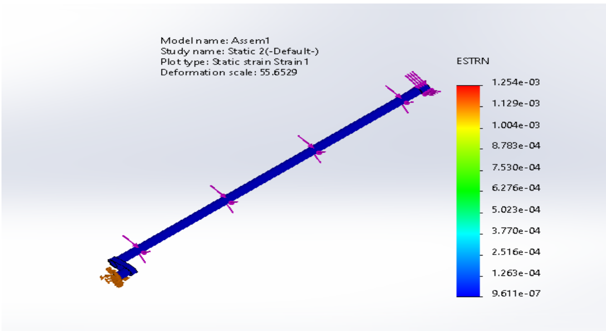
Under the same load, alloy steel may undergo less deformation than carbon steel due to its typically higher strength and resistance to deformation. Alloy steel achieves this through the addition of various alloying elements such as chromium, nickel, molybdenum, and others, which enhance its mechanical properties.

However, it's essential to note that the specific behavior can vary based on the type of alloy steel and carbon steel being compared. Factors such as the carbon content, heat treatment, and the presence of other alloying elements influence the mechanical properties of each steel variant. Alloy steel might be selected when higher strength and resistance to deformation are critical.

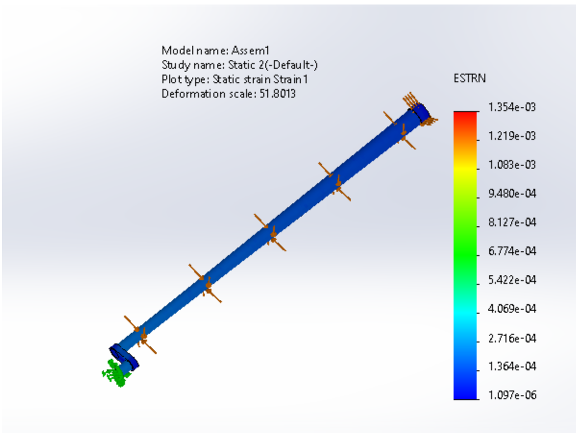
Figure 5 and Table 4 above shows that the total deformation of carbon steel and alloy steel material. The result shows that total deformation in carbon steel 0.00359m and that of alloy steel material is 0.003343m. The value indicates that maximum deformation is achieved by carbon steel material. This indicate that, under the same load, alloy steel may undergo less deformation than carbon steel due to its typically higher strength and resistance to deformation.

Figure 5 and Table 5 shows simulation result or strain energy by both carbon steel and alloy steel material. The energy result indicate that acceptable value of result is that of alloy steel material. Alloy steel, with its tailored composition, may have the capability to absorb more strain energy compared to carbon steel. So, based on these specific properties of carbon steel and alloy steel analysis, the alloy steel material is the optimized material for torsion bar suspension doe to its good strength, and store maximum energy when compared with carbon steel.

4.3 Strain Energy



(A) Strain Energy of Carbon Steel Torsion Bar



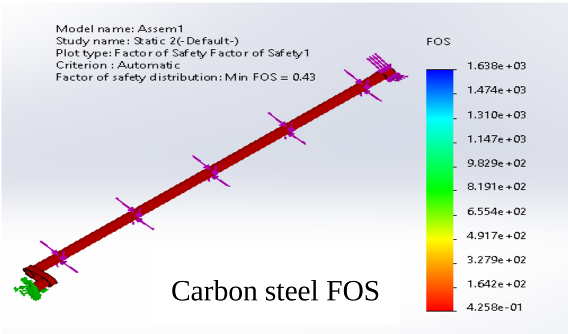
(B) Strain Energy of Alloy Steel Torsion Bar

Figure 6. Torsion Bars under Strain Energy

Table 5. Strain Energy Comparison of Medium Carbon Steel and Alloy Steel Torsion Bar

No	Materials		Strain
1	Carbon Steel	Maximum value	1.354×10^{-3}
		Minimum value	6.8106
2	Alloy steel	Maximum value	1.254×10^{-3}
		Minimum value	9.611×10^{-7}

4.4 Factory of Safety (FOS)



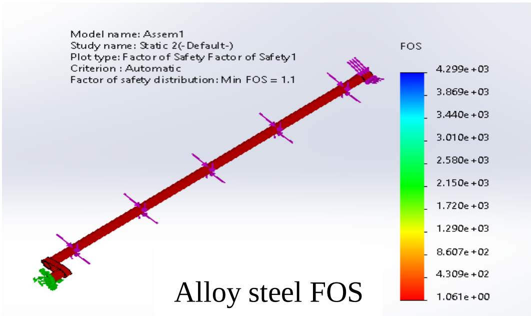


Figure 7. FOS of Alloy Steel and Carbon Steel

As shown in Figure 7 the design is not safe under carbon steel since FOS is less than 1 which is 0.423. But, for alloy steel the design can with stand the twisting load since the minimum FOS is 1.061 which is slightly greater than 1.

5. CONCLUSION

The analysis of the medium carbon 4340 AISI and ALLOY STEEL torsion bar helps us to optimize the better material for improvement of tank mobility with material improvement techniques. According to the analytical calculation and analysis output, alloy steel is the optimized material for the following reasons.

- Alloy steel is often designed to have enhanced mechanical properties, including higher shear strength compared to carbon steel due to addition of alloying elements like chromium, nickel, molybdenum, and others contributes to improved shear strength.
- Analysis shows that design with the given geometry cannot functional for carbon steel, whereas alloy steel can with stand twisting load as minimum FOS is not less than 1.

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Author Contributions Statement

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Ebisa Kejela Melka	✓	✓	✓	✓		✓		✓	✓	✓	✓			

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

Conflict of Interest Statement

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Informed Consent

All participants were informed about the purpose of the study, and their voluntary consent was obtained prior to data collection.

Ethical Approval

Not applicable.

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request

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