

Research Article

# Effect of Heat Treatment on Mechanical Properties and Microstructure of ST 37-2 Rear Trailing Arm (Case study at MIE)

Ashish Thakur<sup>1\*</sup> and Gebre-egziabher Aregawi<sup>2</sup>

<sup>1</sup>School of Mechanical and Industrial Engineering, Mekelle University, Mekelle

<sup>2</sup>Mesfin Industrial Engineering P.L.C, Mekelle University, Mekelle

Received 07 Dec 2018, Accepted 08 Feb 2019, Available online 10 Feb 2019, Vol.9, No.1 (Jan/Feb 2019)

## Abstract

*This paper presents effect of heat treatment (annealed, quench hardened, and tempered) on mechanical properties and microstructure of the rear trailing arm case study at Mesfin Industrial Engineering PLC, Ethiopia. The samples were heat treated in muffle furnace in Mekelle University, Heat Treatment Lab at different temperature levels and holding times; and then cooled in different media. The mechanical properties (tensile yield strength, ultimate tensile strength, percentage reduction, and percentage elongation), bending, impact and hardness of the treated and untreated samples were determined using standard methods and the microstructure of the samples was examined using metallographic microscope equipped with camera. Results showed that the mechanical properties of ST 37-2 steel can be improved by various heat treatments for a particular application. The micrograph revealed that the microstructure of tempered specimen consisted of a number of appreciable carbide particles precipitated out from the matrix, which indicated that the precipitate carbide particles decomposed by a process of solution in ferrite matrix. It was also found that the annealed samples with mainly ferrite structure gave the lowest tensile strength hardness and highest ductility while hardened sample which comprise martensite gave the highest tensile strength and hardness and lowest ductility.*

**Keywords:** Failure analysis, rear trailing arm, microstructure, heat treatment

## 1. Introduction

Suspension system is the most useful component of a vehicle in which its main function is to prevent the road shocks from being transmitted to the vehicle frame, to preserve the stability of the vehicle in pitching or rolling, to safe guard the occupants from road shocks, to provide steering stability with good handling and to provide good road holding while driving, cornering and braking. Elements of vehicle suspension are springs, dampers and connectors trailing arms of body with wheels. Springs are flexible members which act as the reservoir of energy during motion. When vehicles move on a bumpy road, energy is released with the action of damper and energy converted into heat energy consequently the vibration or bouncing of the body is avoided.

A trailing arm design can be used in an independent suspension arrangement. Each wheel hub is located only by a large, roughly U-shaped arm that pivots at one point, ahead of the wheel. Seen from the side, this arm is roughly parallel to the ground, with the angle

changing based on road irregularities. A twist-beam rear suspension is very similar except that the arms are connected by a beam, used to locate the wheels and which twists and has an anti-roll effect. Trailing-arm and multilink suspension designs are much more commonly used for the rear wheels of a vehicle where they can allow for a flatter floor and more cargo room. The trailing arm of Geely Addis assembled by Mesfin Industrial Engineering PLC has been faced with repeatedly failure.

### 1.1 Background of Rear Trailing Arm

Rear Trailing Arm is one of the suspension system components that connect the dead axle and wheel. A trailing-arm suspension, sometimes referred as trailing-link is a vehicle suspension design in which one or more arms (or "links") are connected between (and perpendicular to and forward of) the axle and a pivot point (located on the chassis of a motor vehicle). It is typically used on the rear axle of a motor vehicle.

#### 1.1.1 Working principle of Rear Trailing Arm

Trailing arm is the most visually striking component of a linked rear suspension. In addition to connecting the

chassis, rear axle, and shocks, they provide fabricators with an opportunity for artistic expression. There are some intricate designs, along with some simpler stuff, and have been positively impressed with it all. A trailing arm which has a big job to do, the shocks are mounted to trailing arm so as to support the weight of the vehicle as well as the tension and compression forces generated between the rear wheels and the chassis. Finally, trailing arms need to be strong enough to withstand random hits from rocks, roots, and plain old dirt. Moreover; the trailing arm is used to keep the rear axle from moving left and right during turning. When the body of the automobile is going one way the axle wants to go the opposite side. During this time the trailing arm prevents this destructive action before catastrophic accident has happened. The existing damaged rear trailing arm picture is shown in Fig.1 given below.



**Fig.1.** The existing damaged rear trailing arm

**1.2 Problem statement**

Mesfin Industrial Engineering PLC has been set to get on assembling sedan automobiles the last seven years with the launch of its assembly car, called “Geely Addis,” in collaboration with Geely International Co, a China based manufacturer of Geely cars. Geely International, which was founded in Shanghai in July 2002, recently acquired Volvo, a Swedish brand known for the quality and endurance of its vehicles.

The cars are being initially assembled in semi knocked down (SKD) form, in which parts of the cars are wholly imported from China and assembled at the plant. The company has a long plan to eventually assemble the cars in completely knocked down (CKD) form, in which most parts are produced locally, with the exception of parts like the engines that will be imported.

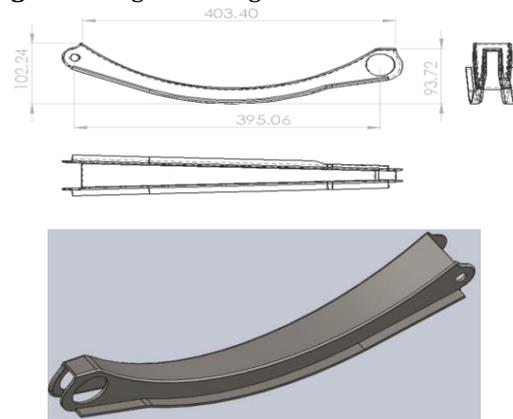
However, its customers are not fully happy due to the failure of some parts. It has been observed that the rear trailing arm fails repeatedly and customers always claim at the company this problem. Among the parts of suspension system which fails repeatedly is the rear trailing arm. It fails due to excessive deformation that tends to be straightened. As a result, the tyre wears quickly due to camber effect. The remedial action which the maintenance personnel always take is only replacing the part by another new one.

The company has a long term plan to bring the full technology of Geely Addis. But it is strictly recommended that it has to study the potential failure

causes and their consequences and to solve problem. Rear trailing arm with damaged part under maintenance is shown in Fig. 2 given below. 3D Modeling and 2D diagram of Trailing Arm is shown in Fig. 3.



**Fig. 2.** Damaged trailing arm under maintenance



**Fig. 3.** 3D Modeling and 2D drawing of the original trailing arm

**1.3 Objective**

**1.3.1 General objective**

The main objective of this research work was to analyze the existing and modified rear trailing arm analytically and propose alternative solution.

**1.3.2 Specific objective**

- i. Mechanical testing of rear trailing arm
- ii. Finding out the cause of rear trailing arm failure

**2. Literature Review**

Different literature reviews which are familiar to the design, modeling and failure analysis of suspension system were inducted for thesis.

#### a) Maintenance and operational manual

Geely Addis operational and maintenance manual from Mesfin Industrial Engineering PLC were taken as a reference for this paper. From the maintenance manual, the Rear and Front Trailing Arms are inspected after every 2 years continues service.

Maintenance documents like job orders and inspection papers are the key references for determining the failure type, occurrence and effects of these failures on the other automobile parts [Geely automobile manual *et al*]. Not only using these documents as an input for this project work but also gathering data from the technicians and maintenance personnel were helpful which can play a crucial role. The technicians conclude that every rear trailing arm they replace become out of use due to excessive deformation.

Therefore, in this paper work, it is proposed to carry out the structural analysis of trailing arm of Geely Addis sedan automobile. Diagram of Rear Trailing Arm from operational manual of Geely Addis is shown in Fig. 4 given below.

#### b) Suspension Lower Arm

The vehicle suspension system is responsible for driving comfort and safety as the suspension carries the vehicle-body and transmits all forces between body and road. Positively, in order influence these properties, semi -active or active components were introduced, which enable the suspension system to adapt to various driving conditions. From a design point of view, there are two main categories of disturbances on a vehicle namely the road and load disturbances. Road disturbances have the characteristics of large magnitude in low frequency (such as hills) and small magnitude in high frequency (such as road roughness). Load disturbances include the variation of loads induced by accelerating, braking and cornering. Therefore, a good suspension design is concerned with disturbance rejection from these disturbances to the outputs. A conventional suspension needs to be "soft" to insulate against road disturbances and "hard" to insulate against load disturbances. Consequently, the suspension design is an art of compromise between these two goals. The general function of control arms is to keep the wheels of a motor vehicle from uncontrollably diverging when the road conditions are not smooth.

In the automotive industry, the riding comfort and handling qualities of an automobile are greatly affected by the suspension system, in which the suspended portion of the vehicle is attached to the wheels by elastic members in order to cushion the impact of road irregularities. The specific nature of attaching linkages

and spring elements varies widely among automobile models. The best rides are made possibly by independent suspension systems, which permit the wheels to move independently of each other. In these systems the unsprung weight of the vehicle is decreased, softer springs are permissible and front - wheel vibration problems are minimized. Spring elements are used for automobile suspension, increasing order of their ability to store elastic energy per unit of weight [A.V. Vanalkaret *al*, 2015; Aniketet *al*, 2014].

Load limits for parts made of materials that strain harden significantly when stressed in the plastic region can be estimated by limit analysis, as can those for parts made of other materials whose stress strain behavior differs from that of the idealized material. In these situations, the designer bases his design calculations on an assumed strength that may actually lie well within the plastic region for the material [D. Goldneret *al*, 1973].

#### c) Static and Fatigue Failure Analysis of Trailing Arm

Suspension system comprises of trailing arm having a leading portion which is coupled to the vehicle chassis and rear end is connected perpendicular to the axle of the system. A bracket is welded at mid-point of the trailing arm where shocks were placed over it. The main function of the trailing arm is to allow the axle to move up and down using the coil spring and limit the movement, when driving on the uneven roads. Because of this the bracket area is highly affected by torsional loading resulting in break torque, hence there will be chances of failure of bracket. In this research, comparison of stresses produced in static analysis and fatigue analysis for the same applied load were carried out [Avinash, C. Suresh *et al*, 2016]. Finally, this research has concluded solving the problem by improving the material property.

#### d) Role of Suspension Lower Arm

Most of the times it is called as a -type control arm. It joins the wheel hub to the vehicle frame allowing for a full range of motion while maintaining proper suspension alignment. Uneven tyre wear, suspension noise or misalignment, steering wheel shimmy or vibrations are the main causes of the failure of the lower suspension arm. Most of the cases the failures are catastrophic in nature. So the structural integrity of the suspension arm is crucial from design point of view both in static and dynamic conditions. As the Finite Element Method (FEM) gives better visualization of this kind of the failures so FEM analysis of the stress distributions around typical failure initiations sites is essential [A.V. Vanalkaret *al*, 2015; Aniketet *al*, 2014].

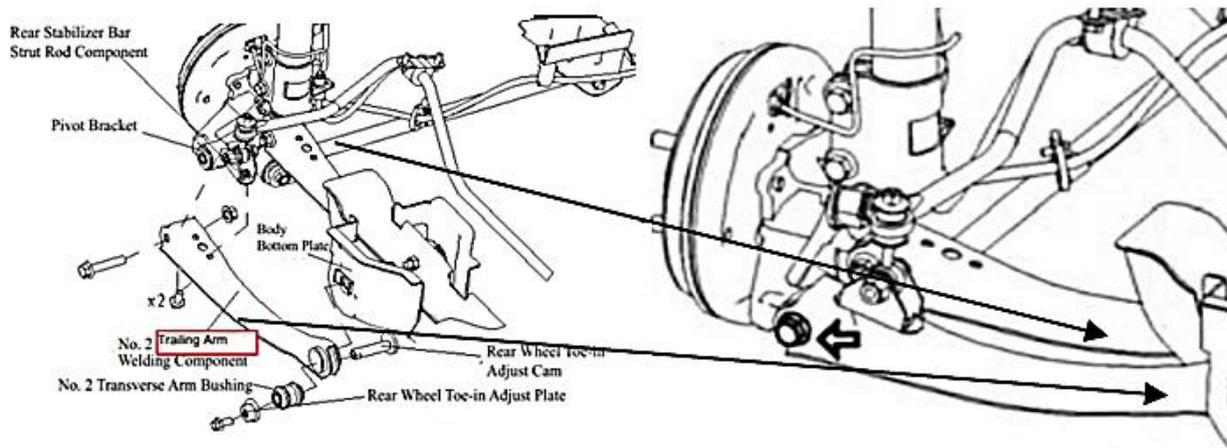


Fig. 4. Diagram of trailing arm taken from operational manual of Geely Addis

e) Working conditions

From the maintenance manual of the automobile, the vehicle is driven under one or more of the following circumstances,

**A. Road Condition**

- i. Drive on rough, muddy or slippery roads [Geely automobile manual *et al*].
- ii. Drive on dusty roads [Geely automobile manual *et al*].

**B. Driving Condition**

- i. Repeat driving within 8km a few times, or when the outdoor temperature is below 0 degree centigrade [Geely automobile manual *et al*].
- ii. Idle the vehicle drive at a low speed for a long time, such as police vehicle, taxi, or door todoor delivery vehicles [Geely automobile manual *et al*].
- iii. Continuously drive the vehicle at high speed for more than 2 hours (80% of the max speed) [Geely automobile manual *et al*].

a) Failure due to overload

Every structure has a load limit beyond which it is considered unsafe or unreliable. Applied loads that exceed this limit are known as overloads and sometimes result (depending on the factor of safety used in design) in distortion or fracture of one or more structural members. Estimation of load limits is one of the most important aspects of design and is commonly computed by one of two methods-classical design or limit analysis.

b) Classical design

This classical approach inherently assumes that the stress to cause fracture is greater than the stress to cause yield. As fracture mechanics analysis clearly shows, this may not be the case. Fracture may occur at

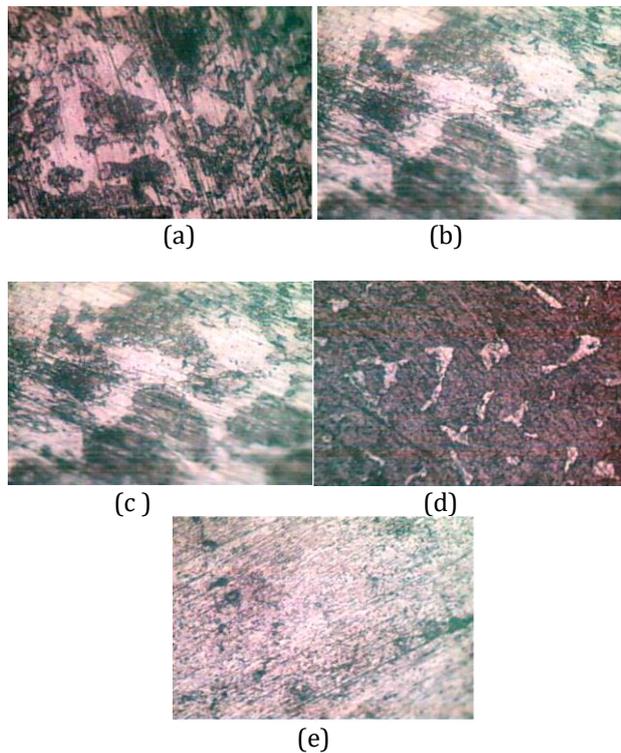
loads less than that required to cause yield if a sufficiently large imperfection is present in the material. Classical design keeps allowable stresses entirely within the elastic region and is used routinely in the design of parts [Shiple *et al*, 1973]. Allowable stresses for static service are generally set at one-half the yield strength for ductile materials and one-sixth for brittle materials, although other fractions may be more suitable for specific applications. For very brittle materials, there may be little difference between the “yield” and ultimate strength, and the latter is used in design computations.

c) Effect of heat treatment on mechanical properties

Annealing, normalizing, hardening and tempering are the most important heat treatments often used to modify the microstructure and mechanical properties of engineering materials particularly steels. Annealing is the type of heat treatment most frequently applied in order to soften iron or steel materials and refines its grains due to ferrite-pearlite microstructure; it is used where elongations and appreciable level of tensile strength are required in engineering materials [M.H.A. Kempester *et al*, 1984; A. Raymond *et al*, 1985]. In normalizing, the material is heated to the austenitic temperature ranges and this is followed by air cooling. This treatment is usually carried out to obtain a mainly pearlite matrix, which results into strength and hardness higher than in as received condition. It is also used to remove undesirable free carbide present in as received condition [K.A. Dellet *et al*, 1989].

The microstructure of untreated specimen given in Fig. 5(a) showed a combination of ferrite (white) and pearlite (black), while the microstructure of the annealed sample is shown in Fig. 5(b). As it can be seen in Figure 5 (b), the ferrite grains had undergone complete recrystallization and these constituted the major portion of the microstructure the annealed medium carbon steel with stress free matrix. At 910°C the deformed structure was fully homogenized and during the slow cooling from austenizing range to room temperature the final microstructure consisted of

fine ferrite grains in which the pearlite was more uniformly distributed. Fig. 5(c) shows the microstructure of the normalized St 37-2 steel [V.B John *et al*; D. A. Fadareet *al*, 2011].



**Fig. 5.** Microstructure observed at 400X for (a) untreated, (b) annealed, (c) normalized (d) hardened, and (e) tempered

Fig. 5(d) shows the massive martensite structure of hardened sample, when low carbon steels are rapidly quenched from its austenite temperature to room temperature, the austenite will decompose into a mixture of some medium carbon martensite and fewer pearlite as a result of this microstructure which is hard, hence, it was increase in tensile strength, hardness and reduction in ductility of the materials [M.H Jokhioet *al*, 1991; A.K. Charkrabartiet *al*, 1974].

Fig. 5(e) micrograph revealed that the microstructure of tempered specimen consisted of a number of appreciable carbide particles precipitated out from the matrix, which indicated that the precipitate carbide particles decomposed by a process of solution in ferrite matrix.

### 3. Material and research methodology

#### 3.1 Material

Materials, the existing rear trailing arm, were procured for conducting tests which was received from Mesfin Industrial Engineering PLC. The samples were prepared from this material to conduct various tests and analysis required in this project work.

#### 3.2 Methodology

In this section, various methods were chosen in order to meet the specific objective and answers to the main problem of the project.

##### 3.2.1 Chemical composition testing

Five samples of existing rear trailing arm from Mesfin Industrial Engineering store were polished by polishing disc to remove the coating and debris. The material composition and grade of the samples were measured by using 6GSO-System Belec compact port spectrometry with high accuracies (C< 0.01percentage) the composition of the material was carried out for identifying the existing elements present in the material using argon gas flushing.

The analysis for the determination of the chemical composition of the plate using spectrometer according to ASTM E 350 – 95 (Reapproved 2000) “Standard test methods for chemical analysis of carbon steel” is depicted in Fig. 6 given below.



**Fig. 6.**Belec compact port spectrometry machine

##### 3.2.2 Heat treatment

After preparation, specimens were heated in muffle furnace at a temperature of 910°C, and were held for 90minutes and then the specimens were quenched into water. After quenching the specimens were again heated for tempering, in this they were tempered at different temperature (650,450 & 250°C). At each temperature three specimens were heated and held for 60minutes, Samples were subjected to different heat treatment: annealing, quench- hardening, and tempering in accordance to International Standards. The heat treatment conditions are listed in Table 1. Four specimens were prepared for each heat treatment type.

**Table 1:** Heat treated conditions

Condition	Annealed	Hardened	Tempering
Temperature,°C	910	910	250, 450 and 650
Holding time, min	90	40	60
Cooling medium	Furnace	Water	Air

### 3.2.3 Mechanical testing

To investigate the root cause of rear trailing arm failure, different types of mechanical testing had been conducted at Mekelle University and Mesfin Industrial Engineering PLC. After successful heat treatment operations, the heat treated specimens were taken for hardness, impact, bending and tensile test to determine the ultimate tensile strength, yield strength, elongation, reduction area and hardness, impact resistance and bend properties. The specimen preparation to conduct

mechanical, hardness, impact, bending and microstructure testing procedure is shown below.

### 3.2.4 Tensile testing

The standard dimension of specimens subjected for tensile strength testing was prepared according to ASTM E8/E8M – 09. The standard specimen size was marked and sketched on the flat stock plate using color marker. Tensile testing specimen drawing is shown in Fig. 7 below.

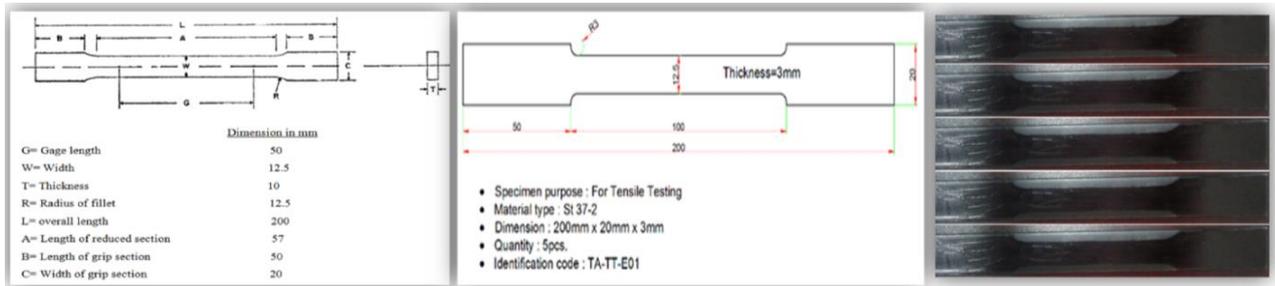


Fig. 7. Tensile testing specimen

### 3.2.5 Hardness testing

The test was performed at room temperature in Mekelle University main campus mechanical engineering material testing laboratory. The test was performed for heat treated and non-heat-treated prepared specimens. These samples were tested at room temperature as per standard hardness testing requirement of ASTM standard. A Specimen after hardness testing is shown in Fig. 8 given below.

### 3.2.6 Bending testing

The sample test was prepared as per ASTM F2273-03 standard. In this test, the specimens are prepared as the drawing shown in the Fig. 9 given below. Bending test was conducted at Mekelle University and the results were recorded carefully.

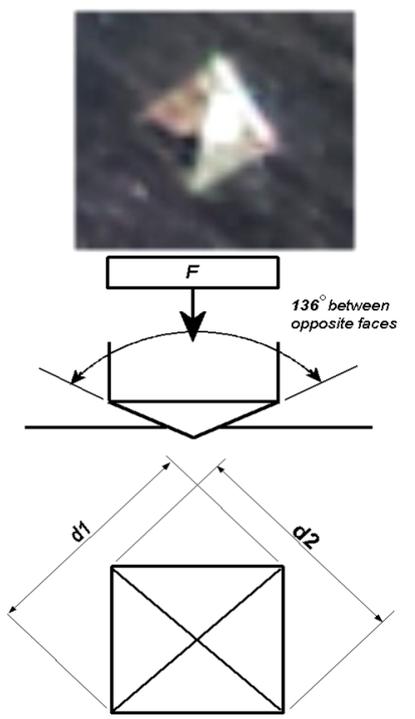
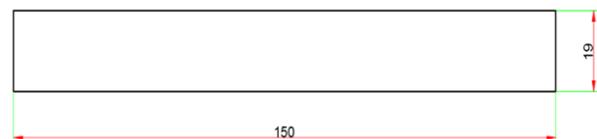


Fig. 8. Hardness testing specimens



- Specimen purpose : For Bending Testing

Fig. 9. Bending test specimens

### 3.2.7 Impact testing

Five samples of specimens from five different existing Rear Trailing Arms were prepared. These samples were tested at room temperature as per standard impact testing requirement of ASTM E23 standard. Impact testing processes for the treated and non-treated specimens are shown in Fig. 10 given below.



Fig. 10. Impact testing process for the treated and non-treated specimens

### 3.2.8 Microstructure testing

Microstructure examination of the treated and untreated samples was carried out. Each sample was carefully grounded progressively on emery paper in decreasing coarseness. The heat treated samples which tested in tensile, bending and impact testing were made ready. They were polished and etched using 2% Nital solution (Nitric acid and methanol). Etch sample with a 2% nital solution (nitric acid and methanol). After standard metallography practices followed to prepare the specimen sent for the microstructure observation. Microscopic examination of the etched surface of various specimens was undertaken using a metallurgical microscope, resulting microstructure of the samples were all photographically recorded with magnification of 400.

## 4. Results and discussion

### 4.1 Results

#### 4.1.1 Chemical composition analysis

The composition analysis of the Rear Trailing Arm samples was carried out using Belec compact port spectrometric machine in MIE. The average composition weight percent results obtained from five specimens of five trials per each specimen and their detail trial results were tabulated. After testing, the obtained composition results for the materials are given in the Table 2 below.

Table 2: Summarized value of the material compositions for Rear Trailing Arm

No.	C	Si	Mn	Cu	Al	Cr	Mo	Ni	V	Ti	Nb	Co	W
Average	0.170	0.105	0.250	0.037	0.096	0.021	0.009	0.005	0.028	0.010	0.080	0.036	0.106
Grade 1: 1.0037, St37-2													

Table 3: Mechanical Properties of heat treated and untreated ST 37-2 steel

Heat treatment	Tensile strength(MPa)	Yield strength(MPa)	Percentage of elongation (%)	Percentage of reduction area (%)
Untreated	436.80	235.22	24.88	29.50
Annealed	416.45	223.17	26.18	30.75
Quench hardened	650.5	315.45	16.35	10.35
Tempered at 250°C	497.6	289.65	20.67	19.43
Tempered at 450°C	480.5	274.15	21.98	24.47
Tempered at 650°C	465.5	261.15	24.37	31.12

#### 4.1.2 Mechanical properties analysis

Five specimens from different five existing Rear Trailing Arm were prepared. The tensile test specimens were subjected to uniaxial load until these were tested by using the Zhejiang SI- 1000KN microcomputer controlled electrohydraulic servo universal testing machine. The test was performed at standard room temperature in Mekelle university main-campus civil (structural) engineering material testing laboratory. Tensile testing of the original Rear Trailing Arm at Mekelle University is shown in Fig. 11 given below.



Fig. 11. Tensile testing of the original Trailing Arm at Mekelle University

The effect of heat treatment (annealing, quench-hardening, and tempering) on the mechanical

properties (ultimate tensile strength, hardness, percentage elongation, and percentage reduction) of the treated and untreated samples is shown in Table 3 above.

### 4.1.3 Impact testing

Average results of the Charpy's V-notch impact energy values in joules obtained are given in Table 4 below.

**Table 4:** Average impact energy values of untreated and heat treated specimens

Heat treatment	Average Charpy V notch impact energy in Joules
Untreated(existing rear trailing arm)	29.4
Annealed	22.3
Quench hardened	46
Tempered at 250°C	46
Tempered at 450°C	44.7
Tempered at 600°C	43.2

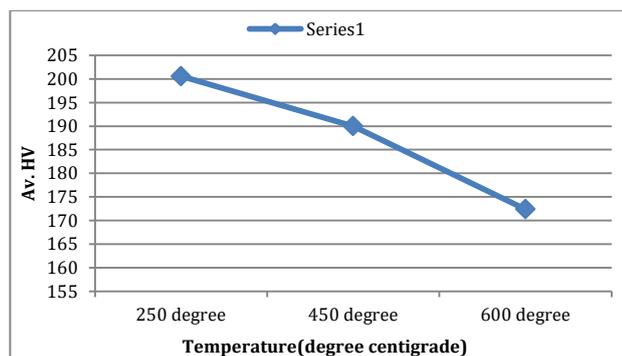
### 4.1.4 Hardness testing

Average hardness value of original Rear Trailing Arm (existing) and heat treated specimens are given in Table 5 below.

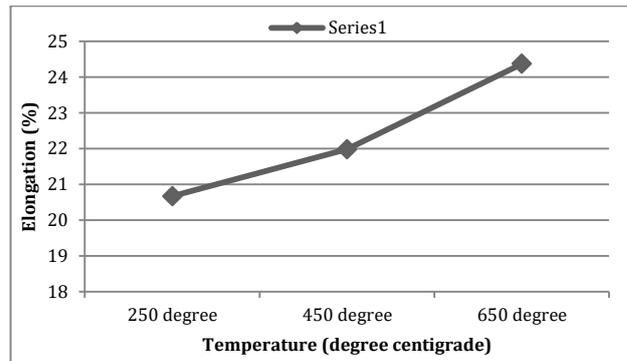
**Table 5:** Average hardness values of untreated and heat treated specimens

Heat treatment	Average Hardness value (HV) in Joules
Untreated(existing rear trailing arm)	146.4
Annealed	132
Quench hardened	160
Tempered at 250°C	200.6
Tempered at 450°C	190
Tempered at 600°C	172.4

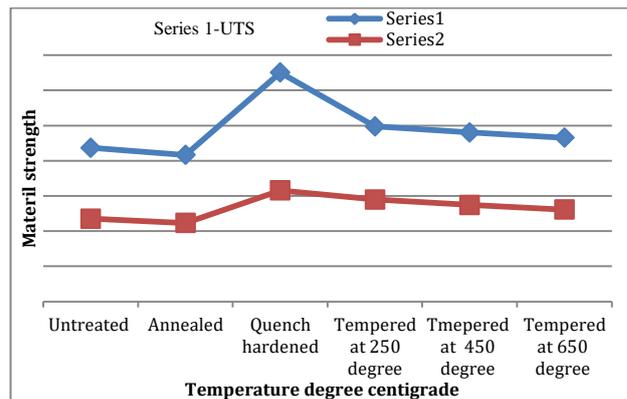
The hardness property of tempered specimens is measured as function of tempering temperature using Vickers hardness tester. The results obtained from testing of specimens quenched at 910°C and tempered at temperature 650, 450 and 250°C hold for 60 minutes. For comparative studies to inquire relationship, temperature vs hardness, temperature vs % of elongation, and temperature vs material strength are shown in Fig. 12, 13 and 14 given below.



**Fig.12.** Effect of tempering temperature on hardness for different tempering temperature



**Fig.13.** Effect of tempering temperature on elongation for different tempering time



**Fig. 14.**Effect of tempering temperature on ultimate tensile strength and yield strength for untreated, annealed, quench hardened and different tempering temperature

### 4.1.5 Bending testing

The most common purpose of bending test is to measure flexural strength and flexural modulus. Flexural strength is defined as the maximum stress at the outermost fiber on either the compression or tension side of the specimen. Flexural modulus is calculated from the slope of the stress vs strain deflection curve. Specimens after bending testing are shown in Fig. 15 given below.



**Fig. 15.** Specimens after bending testing

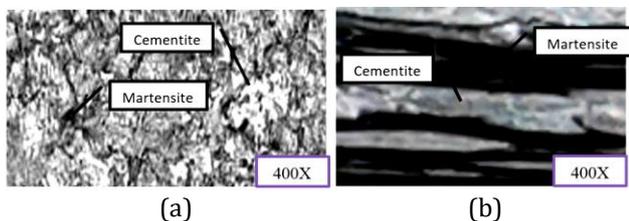
The results from bending strength testing had been obtained upper and lower results. Bending test results of existing Rear Trailing Arm samples and heat treated samples are shown in Table 6 given below.

**Table 6:** Average bending test results of untreated and heat treated specimens

Heat treatment	Average flexural strength value in MPa
Untreated(existing rear trailing arm)	428.6
Annealed	410
Quench hardened	475
Tempered at 250°C	496
Tempered at 450°C	473
Tempered at 600°C	450

4.1.6 Microstructure

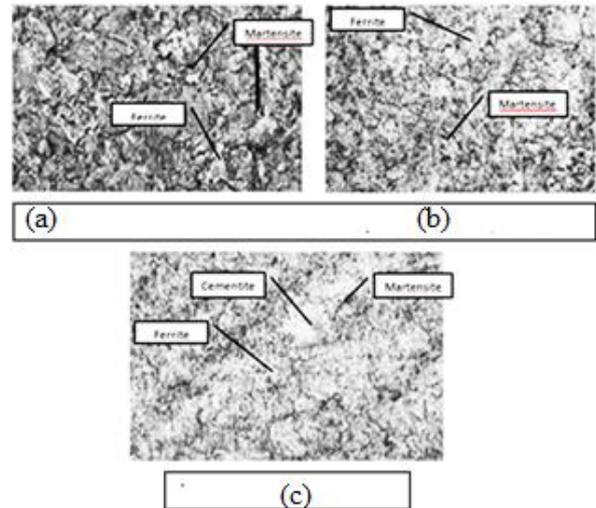
The aim of the study was to determine the microstructure which appears in the St37-2. The changes of orientation, both morphological and crystallographic, are occurring as a result of the rolling process. The observed microstructural changes were correlated with the mechanical properties results of destructive testing done. Microstructure of non-heat treated specimens (a)microstructure of the existing rear trailing arm after tensile testing (b) microstructure of the existing rear trailing arm after impact testing are shown in Fig. 16 given below.



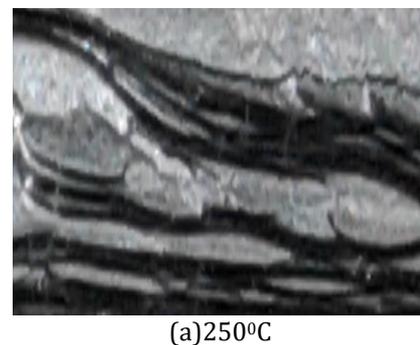
**Fig. 16.** Microstructure of non-heat treated specimens (a) existing rear trailing arm after tensile testing (b) existing rear trailing arm after impact testing

Microstructure observed for non-heat treated specimen at 400X and it was observed from Fig. 16 given above that there is a fusion of cementite and martensite zone in the INSET of image in the case of Trailing arm after tensile test. It was also observed that the cementite and martensite zone as the bay type fusion zone at 450 degree tempered microstructure image taken at 400X in case of specimen after impact testing.

Microstructure of heat treated tensile specimens picked at 250°C, 450°C and 650°C were taken at 400X using the optical microscopes shown in Fig. 17 given below. It is observed that carbon particle is like a stain in the middle part of the inset surface while cementite of little variation can be found in the whole surface in segregating but carbide in the form of ferrite but percentage is high at 250°C while in cementite a little higher in comparison to 450°C. Little martensitic is also observed at 450°C when it is compared to 650°C. It is observed that particles are distorted and distributed of the bulk cementite is higher in comparison to 250°C and 650°C. Recrystallization is no more, however brittleness is shown at 650°C and at hence strength is less. Microstructure of heat treated impact testing specimen at those three tempered specimens are shown in Fig. 18 given below.



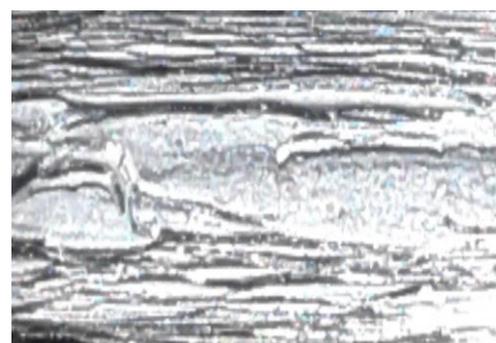
**Fig. 17.** Microstructure after tensile testing (a) 250°C (b)450°C and (c) 650°C



(a)250°C



(b) 450°C



(c) 650°C

**Fig. 18.** Microstructure of heat treated after the impact testing

### Alternative Proposed solution selection

As it is indicated from the very beginning, the existing rear trailing arm material was ductile and soft. It was observed that the mechanical property can be improved by heat treatment. Though, exiting materials was failed statically, it might be due to lower safety factor as well as mechanical property could not sustained enough and it deformed at lower load. Solution could be optional, either it can work by changing the composition or replaced by other materials which have better mechanical properties rather than exiting materials.

Two proposed solution could be the heat treatment and change in thickness of materials analytical work both.

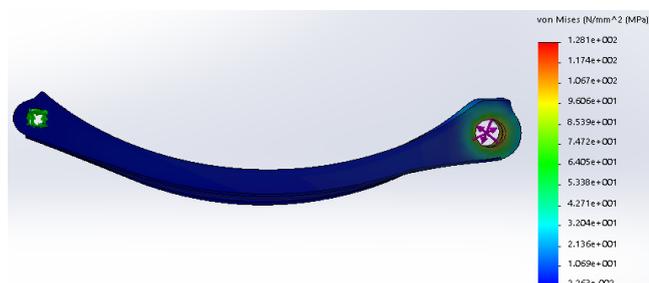
#### (i) Static analysis of the modified design of Rear Trailing Arm

In the modified design model, the thickness and material property was improved by changing 2mm to 5mm of St-37 material quality. Static structural analysis is carried out for the modified design under 3G bump load condition for each material types.

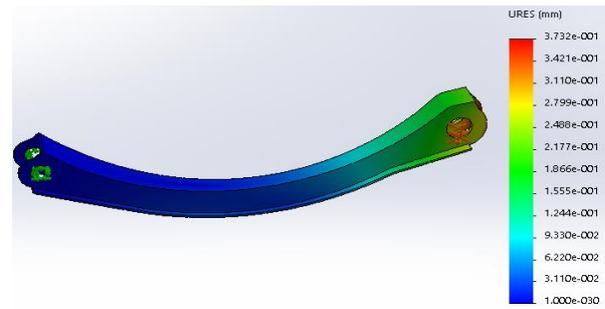
The von mises stress observed for 3G load condition of the Rear Trailing Arm is 128.1MPa for St-37, which lies within the yield limit of the material. Von Mises Stress for modified design of Rear Trailing Arm is shown in Fig. 19 given below. Hence the design is safe. Fatigue analysis was also carried out for the tempered modified design of Rear Trailing Arm. Deformation for the modified design Rear Trailing Arm graph is shown in Fig. 20. Damage percentage of Rear Trailing Arm (a) existing (b) heat treated samples is shown in Fig. 21 given below. Static stress analysis result for St-37 Rear Trailing Arm is shown in Table 7.

**Table 7:** Static stress analysis result for St-37 Rear Trailing Arm

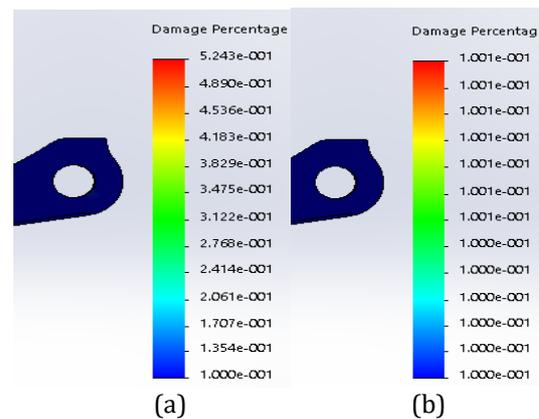
Type of load	Material type	Von Mises Stress (MPa.)	Static factor of safety
3G	St-37	128.1	1.83



**Fig. 19.** Von Mises Stress for modified design of Rear Trailing Arm



**Fig. 20.** Deformation for the modified design Rear Trailing Arm



**Fig. 21.** Damage percentage of Rear Trailing Arm (a) existing (b) heat treated

The summarized result analysis for the existing and heat treated modified Rear Trailing Arm under 1G, 2G and 3G loading conditions is tabulated in Table 8.

**Table 8:** Summarized static and dynamic factor of safety for existing and modified Rear Trailing Arm

Material type	Thickness in mm	Loading type	FOS static	FOS dynamic
St-37 (Existing Rear Trailing Arm)	2	1G	1.31	0.53
		2G	0.66	0.26
		3G	0.44	0.17
St-37	2	1G	1.31	0.53
			1.69	0.68
			5.47	2.19
	2	2G	0.66	0.26
			1.03	0.41
			2.76	1.11
	2	3G	0.44	0.17
			0.69	0.28
			1.83	0.73

### 4.2 Discussion

Experimental tests analysis like chemical compositions as well as mechanical tests were carried out for existing St-37. Material grade St-37 was confirmed from the average composition weight percent results obtained from the chemical testing experiment carried out using Belec Spectrometer.

The other experiments were carried out which helped to know the mechanical property of the existing Rear Trailing Arm were tensile, bending testing, impact

testing, hardness and microstructure testing. Heat treatment was carried out in support of materials properties investigations for existing rear trailing arm St-37 material.

Mechanical testing was carried out using materials testing system for heat treatment and non-heat treated existing rear trailing arm. The average value of yield strength and tensile strength of the existing rear trailing arm were found 235.22MPa and 436.8MPa respectively. The average value of the impact testing and hardness results found after heat treated tempered specimens were 46 Joules and 200. 6HV is much higher in comparison to existing trailing arm. From this result, it can be said that the existing Rear Trailing Arm is soft and ductile material.

Bending test results of existing and for heat treated samples were performed at room temperature. Average bending strength results of existing Rear Trailing Arm was found 428.6MPa lower in comparison of 496MPa of heat treated tempered specimens.

The hardness test specimens were subjected to an indentation of diamond shape indenter of 100kgf. The indentation was maintained to 15Secs. An average hardness value of heat treated specimens was found higher in comparison to the non-heat treated specimen of existing St-37.

Microstructure which had been taken by the optical microscope with a magnification of 400X for all specimens after the tensile and impact testing were done. A tensile and impact test specimens were observed under optical microscope and it was informed that there is almost equal distribution of ferrite and pearlite. This implies that failure might have occurred due to ductile failure. Microstructure observed after ferrite and impact tests, indicates that there is almost equal distribution of ferrite and pearlite. The reason is that the dusty ferrite and impact crystals are broken in percentage and stress is relieved at high load. Recrystallization was not observed any more, however brittleness is shown at 650°C after tensile testing. It is observed from that at 450°C is a less cleavage is there in comparison to 650°C and it clearly seems that brittle fracture occurred after impact tests. The micrograph revealed that the microstructure of tempered specimen consisted of a number of appreciable carbide particles precipitated out from the matrix, which indicated that the precipitate carbide particles decomposed by a process of solution in ferrite matrix.

The existing material trial analysis was experimented by changing with an incremental material thickness from 2mm to 5mm and they were analyzed static and fatigue under 3G bump load condition. The maximum stress produced in the new heat treated modified rear trailing arm was 128.1MPa for 3G bump load condition. The modified heat treated rear trailing arm has been observed safe with factor of safety 1.83 and 0.73 static and dynamic respectively.

## Conclusion

The objective of this study is to make an analysis on how the rear trailing arm fails. To achieve it, heat

treatment was done for St-37 but result indicated that it is not much suitable for trailing arm suspension load. Heat treatment and FEA both by changing in thickness could achieve the objective. Visual inspection, mechanical properties tests and microstructural observation was carried out through the heat treatment. FEA to study the stress and fatigue analysis were carried out on the existing component and heat treated modified trailing arm. From the practical observation, it was found that the rear trailing arm gets out of use after a minimum deformation of 2.0 mm in length.

From the results of investigation on the effect of heat treatment on mechanical properties and microstructure of ST 37-2 steel, the following conclusions were made:

The results show that the ultimate tensile strength and some extent the yield strength decrease, whereas the elongation increases with increase in tempering temperature. The higher is the tempering temperature, the lower is the hardness or the more is softness (ductility) induced in the previously quenched specimen.

Tensile strength, yield strength and hardness of medium carbon ST 37-2 steel increased with plastic deformation while ductility decreased due to strain hardening effect. Quench hardening treatment had also resulted in higher tensile strength and hardness than annealed samples. This treatment is recommended as final treatment after manufacturing.

The tempered samples gave an increase in tensile strength and hardness than untreated sample as a result of formation of tempered martensite and resultant ferrite structure that were obtained. Hardened sample had the highest tensile strength and hardness with lowest ductility when compared to other heat treated samples. Quench hardening is strongly recommended when the strength and hardness are the prime desired properties in design. The mechanical properties of ST 37-2 steel can be altered through various heat treatments. The results obtained confirmed that improvement in mechanical properties that can be obtained by subjecting ST 37-2 steel to different heat treatments investigated in this study.

Bending, hardness and impact test results of existing and for heat treated samples were performed at room temperature. A result shows that a high amount of incremental changes in strength were observed for heat treated specimens in comparison to existing rear trailing arm.

A tensile and impact test specimens were observed under optical microscope and it was informed that there is almost equal distribution of ferrite and pearlite. This implies that failure might have occurred due to ductile failure. The reason is that the dusty ferrite and impact crystals are broken in percentage and stress is relieved at high load. Recrystallization was not observed any more, however brittleness is shown at 650°C after tensile testing. It is observed from that at

450°C is a less cleavage is there in comparison to 250°C and it clearly seems that brittle fracture occurred after impact tests.

The damage plot shows the percentage of the existing Rear Trailing Arm's life consumed by the specific fatigue event. The fatigue event consumes 0.52 %, while modified heat treated Arm's life consumed by the specific fatigue event is only 0.1 %. The new modified design is statically and dynamically safe. The modified heat treated rear trailing arm has been observed safe with factor of safety 1.83 and 0.73 static and dynamic respectively.

### Acknowledgements

We would like to express our thanks to department of Mechanical Engineering, Solid Mechanics Chair and Mesfin Industrial Engineering for allowing us to use their laboratory.

### References

- Kempester M.H.A (1984), (3<sup>rd</sup>ed.), *Materials for Engineers*, Hoodder and Stonghton.
- Raymond A., and Higgins B,(1985), *Properties of Engineering Materials*, Hoodder and Stonghton.
- Geely automobile manual.
- Vanalkar A.V. (2015), Design, Modeling and Failure Analysis of Car Front Suspension Lower Arm, *International Journal of Science Technology & Engineering*, 2(01).

- Aniket Thosar(2014), Design, Analysis and Fabrication of Rear Suspension System for an All-Terrain Vehicle, *International Journal of Scientific & Engineering Research*, 5( 11).
- Goldner D. (1973), Plastic Bending in Tubular Beams, *Mach. Des.*, 45 (24).
- Avinash C. Suresh (2016), Static and Fatigue Failure Analysis of Trailing Arm Bracket of Rear Suspension System, *International Journal of Innovative Research in Science, Engineering and Technology*, 5(7).
- Shipley and David A. Moore, *Analysis of Distortion and Deformation*, Packer Engineering and William Dobson, Binary Engineering Associates, Inc.
- Dell, K.A (1989), *Metallurgy Theory and Practical Textbook* (American Technical Society, Chicago, 351-353).
- John, V.B, *Introduction to Engineering Materials*, 2<sup>nd</sup> Edition. Macmillan Publishing Company Ltd., 321-324).
- Fadare D. A., Fadara T. G. and Akanbi O. Y.(2011), Effect of Heat Treatment on Mechanical Properties and Microstructure of NST 37-2 Steel, *Journal of Minerals & Materials Characterization & Engineering*, 10(3), 299-308.
- Jokhio, M.H.(1991), *Effect of Retained Austenite on Abrasive Wear Resistance of Carburised SAE 8822H Steel*, Thesis in Manufacturing Engineering, Mehran University of Engineering and Technology, Jamshoro.
- Charkrabarti, A.K. (1974) and Das, Kinetics of Second stage graphitization in Quenched Alloy Spheroidal Iron, *Journal of British Foundry man*, 67, 330-334.