Investigation of micro-structure and mechanical properties of three steel alloys

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ABSTRACT

The significant demands of steel in industrial applications and automotive and building industries are increasing. Thus, there is a need for the improvement of its mechanical properties by adding suitable alloy elements to them so that they have more strength-weight ratio. The objective of this research is to study the effect of adding various alloys to steel material and their effects on tensile and impact strengths, hardness, and microstructure. The tensile test was conducted on a round bar standard specimens of three kinds of steel having different compositions to investigate their mechanical properties. The results of tensile tests are given in tables, based on their stress-strain curves plotted to facilitate the design engineer to know the strength and accordingly design lightweight structures from this material. After the test, the microstructure of the fracture surface was observed using an inverted microscope. The tensile and impact strengths and hardness of carbon steel, EN 8 steel, and mild steel were evaluated and compared based on the chemical composition and microstructural observation. The experimental result showed that the increasing percentage of carbon and silicon in EN 8 steel increased its ultimate tensile and yielded strengths but reduced the percentage elongation compared to carbon steel. Similarly, less content of manganese with an increased content of nickel enhanced the impact strength of the mild steel but slightly reduced the tensile strength and hardness of mild steel compared to EN 8 steel.

Keywords: Steel alloy; mechanical properties; microstructure; fracture; strain rate.

INTRODUCTION

There is a high demand for steel members having the capacity to take more loads in less area; i.e., steels having more strength-weight ratio. For a design engineer, to use a material in thin sheet form, they must have accurate and reliable data of the tensile and impact strengths of the materials. The mechanical properties and microstructure of the steel materials vary with the addition to chemical composition and also by hot and cold forming processing. Generally, steel shows a yield point at the elastic limit. Ductility of steel is measured by elongation and reduction of area. Designer faces a challenge to select the optimal composition of steel material because an increase in the strength of steel alloys is always accompanied by a decrease in elongation. To avoid this, proper investigation of each constituent of the alloys in steel tested should be conducted to get the strength versus elongation values. The tensile test gives detail information on the steel alloys on strength and ductility during uniaxial applied loads. This information is vital for a design engineer to select proper materials under different circumstances used in industrial/construction

applications. Steel is an alloy of iron and carbon with other alloy elements to improve mechanical properties. It is one of the most important engineering materials significantly used in industrial applications, building structures, automotive industries, and power plant engineering applications in the form of beams, rods, plates, tubes, and sheet metals. Depending on the percentage of carbon contents, steel can be classified as low carbon steel ($\%C < 0.3$), medium carbon steel ($0.3 < \%C < 0.6$), eutectoid steel ($\%C = 0.8$), and high carbon steel ($0.8 < \%C < 1.2$). These steels have been widely used to manufacture large diameter pipes for oil and gas transportation and in the form of heavy plates that can be used for naval ship construction [1]. The mechanical properties of metals and its alloys can be improved by a combination of metallurgical, manufacturing, and design measures, which increase the reliability and service life of the manufactured component [2]. The impact of tensile properties of Cu-Ni alloy was investigated by using post-irradiation annealing and found to increase the annealing temperature and time yield strength as well as tensile strength [3]. An experiment was conducted on the fine-grained microstructure in copper and the test result was compared by applying uniaxial tension and compression force [4]. The production of low-cost steel is by reducing the content of Co, Mn, and Cr as well as investigating the impact of reduced alloys on mechanical properties and microstructure of steel [5]. The carbon content is important for providing a variety of strength and hardness by changing its composition in steel. The designer should have an idea of the modulus of elasticity, yield and ultimate tensile strengths, ductility and hardness of the material while designing a steel member for the industrial applications or structure members. The tensile, impact, and hardness tests give all the above details to designers to decide the failing criteria of the members during dynamic application of load on steel alloys. The alloys added to iron not only improve the mechanical properties but also enhance the anti-high temperature corrosion performance and oxidation resistance. For example, Si is added to improve oxidation resistance by forming a protective passive layer of SiO_2 and also improves the mechanical properties at high temperature [6]. The research investigated the effect of Ni in addition to improve mechanical properties at room temperature [7]. This paper gave details on the effect of Cr addition to improve the resistance to high-temperature oxidation properties and also influence on the phase transformation and liquid temperatures [8]. The mechanical and electrical properties of the Cu-Ag alloys have been studied during cold working operations and it was found that by adding a percentage of Cr, tensile strength increases whereas electrical conductivity decreases [9]. A research investigated the microstructural behaviour and mechanical properties of copper and brass alloys by the tensile and impact tests and found that during dynamic loading, brass showed a high strength with reduced ductility [10].

The hardness of a material is the resistance to penetration of the surface by a hard indenter. The hardness of a material correlates with wear resistance, especially when manufacturing gear teeth in the transmission or the drive system of a vehicle requires harder material. Mild steel has definite yield point. It contains less than 0.3% carbon. Medium carbon steel contains 0.3% to 0.8% carbon. High carbon steel contains 0.8% to 1.2% carbon. As the carbon content increases the strength also increases but ductility is reduced. The high carbon steel does not show clear yield point. The modulus of elasticity (E) defines the properties of a material as it undergoes stress, deformations, and then returns to its original shape after the stress is removed. It is a measure of the stiffness of a given material. The yield strength is the stress at the point in the stress-strain curve, where plastic deformation is noticeable. The ultimate tensile strength is the stress at the highest applied force at which necking begins and requires a lower force to continue further deformation in ductile materials. Ductility is the amount of deformation material that can withstand without breaking and has significant factors for designers and

manufacturers, especially considering forming operations like rolling and extrusion. The elongation value during the test also depends on the gage length. The smaller the gage length the higher the localised strain in the necked region. According to Arlazarov et al., austenite grain size can be reduced by cold rolling after double annealing to a 0.092% C-4.6% Mn wt% steel to investigate the mechanical properties and microstructure as a function of inter-critical annealing time with Mn segregation. They found that true stress is directly linked to holding temperature and time [11]. Saleh et al. [12] investigated the mechanical properties of composite materials by the tensile, impact, and creep tests and found that CKCF carbon composites have better mechanical properties in comparison of CRCF and CYCF carbon composites. Hariprasad et al. [13] investigated the tensile and impact strengths of an alkali-treated banana-coir epoxy hybrid composite and found that tensile and impact strengths are more than untreated banana-coir epoxy hybrid composite, whereas the flexural strength of the untreated banana-coir epoxy hybrid composite was more. The content of manganese is usually limited to reduce solidification segregation and by combining with Sulphur that reduces the chance of solidification cracking. Similarly, the content of nickel improves the toughness and adds a solid solution hardening effect [14]. The increased content of chromium enhances the tensile strength and hardness of the steel alloys, which further increase by the larger impact of manganese at low concentrations [15]. The research found that optimum content of Si in T91 grade steel provides desired impact strength after an investigation within temperature region -40 to 440 °C using the Charpy Method [16].

The main objective of this research is to investigate the changes in mechanical properties of the steel alloys as a result of variation in the composition of the alloying elements. The tensile and impact strengths and hardness of carbon steel, EN 8 steel, and mild steel alloys were investigated with the variation composition of 3C, 3Mn, 3Si, 3P, 2Cr, and 2Ni percentage present in the steel alloys. This research also investigated the microstructural behaviour of steel alloys using an inverted microscope. This article is organised as follows; Section 2 illustrates test materials and experimental methods. Results and discussions are presented in detail in Section 3, while Section 4 gives the concluding remarks.

METHODS AND MATERIALS

This research considered steel alloys to study the impact of alloys addition on mechanical properties of the material. The chemical compositions of the alloys are shown in Table 1. Annealing is the heat treatment process to improve the mechanical properties and microstructure of steels by refining its grain due to ferrite-pearlite microstructure [17]. The impact of heat treatment on microstructure and mechanical properties of martensitic steel was studied and hardness and toughness of steel were found to retain around 61.6 HRC and 20 J due to the high carbon martensite and fine grain size when quenched up to 1100 °C [18]. The impact of isothermal tempering on the microstructure and mechanical properties of high Co-Ni secondary hardening ultrahigh strength steel was analysed and steel was found to retain the tensile strength of value 2222 MPa and a hardness value of 56.5 HRC with prolonged tempering time although toughness reduced with the increase of tempering time [19]. According to Mathew and Rajendra Kumar, the Taguchi-Grey method was applied to investigate the effect of boronisation process parameters on tensile properties of low carbon steel and carburised carbon steel. They found that ultimate tensile strength is influenced by the boronising temperature more than process time and carbon content [20].

Table 1. Chemical compositions of the steel used.

Alloy Names	C	Mn	Si	S	P	Cr	Ni	Fe
Carbon Steel	0.12	0.980	0.05	0.28	0.05			Balance
EN-8 Steel	0.452	0.780	0.230	0.011	0.024	0.010	0.001	Balance
Mild Steel	0.182	0.717	0.228	0.010	0.031	0.007	0.002	Balance

To investigate the mechanical properties of steel, standard test procedures were considered by using standard test specimens. Specimens of each material were tested at room temperature on GUNT Universal Testing Machine (UTM) with constant crosshead movement of 2 mm/min for the tensile strength of the material [21]. An extensometer was used to calibrate and measure the sample strain upon loading. Tensile tests were performed at room temperature on a cylindrical specimen with a gauge length of 30 mm with 6 mm diameter for carbon steel and 5.7 mm diameter for mild steel specimen, whereas for EN 8 steel alloy the gauge diameter and lengths were 5.8 mm and 33 mm, respectively. The tests were run under constant and continuous application of load at an initial strain rate of 1.3×10^{-4} s^{-1} for all steel alloys on a GUNT Universal Tensile Machine (UTM). The specimens were loaded continuously until failure. The impact test was carried out on GUNT pendulum impact tester of 300 Nm maximum capacity for a specimen dimension of $55 \times 10 \times 10$ mm in length, width, and height. The microstructure of the fracture surface of the specimen after the tensile and impact tests was examined using an inverted microscope after polishing it using nital etchant 2% HNO_3 and 98% ethanol for all three steel alloys for 15 seconds. Rockwell hardness test was carried out on each specimen using the universal hardness testing machine in F scale with 1/16 in. steel ball indenter and 100 Kg applied load. The mechanical properties of AA 6060 and 6061 were observed during experimental analysis by varying compositions of Mg alloy to the aluminium alloy tested [21]. An experiment was conducted on welded joint and the weld current nugget increased with the increasing diameter and further increased the loading force. However, by increasing electrode pressure the applied force value will decrease during tensile test [22]. An experimental analysis was conducted on Cu and brass alloys to observe the mechanical properties by varying their compositions on tensile strength [23]. The grain refinement caused by the alloying elements Fe-18Cr-16Ni is the source for the decrease in elongation whereas increase in tensile strength [24]. The addition of Cr improved the tensile strength similarly by addition of Ni that improved the tensile strength but also delayed delamination associated with strain [25]. The addition of Mn content into alloys does better grain refinement process that has a little-improved elongation than the Mn-free alloys. Similarly, the deviation of tensile strength is unequal and by the addition of Mn, the content alloys have higher ultimate tensile strength than the Mn-free alloy [26].

The tensile test is used to determine the tensile strength of a material and also measure the elongation at fracture. During the test, the specimen was fixed in the grip holder of the testing machine in such a way that the load can be applied axially and a single-axis stress state has been generated to the specimen in a longitudinal direction. This results in a uniform normal distribution of stress across the test cross-section of the specimen. Bearing the load indicates pointer of the dial to zero and applied the load slowly and continuously by turning the hand wheel until it breaks. The resulting maximum test force is a measure of the material's strength called ultimate tensile strength R_m in N/mm^2 calculated from the maximum test force F_B in N, determined from the force-elongation diagram and the initial cross-section A_0 of the specimen in mm^2. The elongation at fracture is the change ratio in length of the specimen to its original length L_o and

calculated by measuring the length L_u of the specimen after fracture. The result of the tensile test has been represented in a stress-elongation diagram. From the graph, the ultimate tensile strength R_m, proportionality limits R_p, yielding point R_e, and fracture strength R_f were calculated and reported in Tables 2-4 for all three specimens. Generally, hardened steel virtually ruptures without plastic deformation but has high tensile strength, tempered steel is far tougher but still has a high strength, while the soft annealed steel has a very high elongation but a low tensile strength.
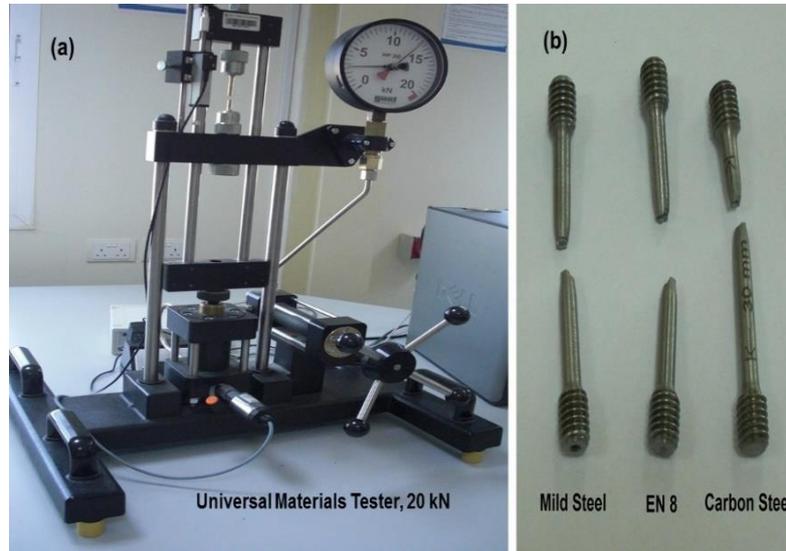
Figure 1. (a) Universal Testing Machine (UTM) and (b) specimen after fracture.

Tensile Test
The tensile test is a standard test conducted on GUNT universal testing machine with standard test specimens. From the literature survey, it was found that many varieties of tensile specimens with different dimensions have been used by different authors based on the availability of materials. In many cases, the specimen's dimensions were other than dictated by ASTM. They have investigated the impacts of specimen size and geometry on the tensile strength of pure ultra-fine-grained copper [27]. The tensile property of two materials has been investigated and the impacts of changing the gage length on mechanical properties observed [28]. This research considered the standard specimens for steel material to find tensile strength of the materials. Three test pieces of each material like carbon steel, EN 8 steel, and mild steel have been used for determining the tensile strength of all materials on UTM. The mechanical behaviour of each specimen was determined from the tensile test data of the specimen. A diameter of 6 mm and 30 mm gauge length (L/D ratio is 5) with 64 mm of total length for carbon steel, 5.7 mm gauge diameter, gauge length of 30 mm for mild steel alloys, and a specimen for gauge diameter 5.8 mm and gauge length of 33 mm with total length of 67 mm for EN 8 steel alloys were used for the experimental analysis. Researchers did experimental analysis on Cu, Al, Au, and Ni foils with a thickness less than 250 μm and it has been observed that yield strength increased while tensile strength decreased by the decreasing thickness of foil [29, 30]. Figure 1 shows the experimental setup for tensile test on UTM of each specimen and fractured specimens after the test.

The tensile test was carried on UTM of 20 KN capacity at across head speed of 2 mm/min, where the load-deflection curve was obtained for each specimen. Data were generated during the test like applied load, elongation, stress and percentage elongation

in the table and graphs and curves were plotted for each specimen by continuous application of load until fracture. After the test, the yield, tensile, and fracture strengths, and ductility were measured while the fracture surfaces were examined using an inverted microscope. From the literature survey and experimental observation, it was found that tensile properties of specimens were dependent on the annealing temperature as well as time by increasing, reducing and ductility improving any tensile strength normally. From the tensile test data generated, it was observed that the tensile properties changed with annealing temperatures. It was determined that carbon steel and EN 8 sheet of steels showed continuous yielding behaviour whereas mild steel showed discontinuous yielding. According to Fang et al., steels showing continuous yield have proven stress at 0.2% strain called yield strength while ferrite-martensite steels showing discontinuous yield was due to high dislocation density surrounding the martensite islands [31].

Carbon Steel (S9Mn28)
Gauge length (l_0) = 30 mm, gauge diameter (d_0) = 6 mm and increased length (l_u) = 42 mm reduced diameter (d_f) = 4.3 mm. Data collected during the tensile test are shown in Table 2. Figure 2 shows the increase in length after the failure of the specimen in the tensile test while Figure 3 shows the stress-percentage elongation graph in software supporting the tensile test.

Table 2. Tensile Test result for carbon steel material

S. No.	Load P (N)	Elongation e (mm)	Stress $\sigma = \dfrac{P}{A_0} (N/mm^2)$	% Elongation $EPS = \dfrac{e}{l_0} \times 100$	Stress at Yield Point, Maximum load, Break point. (N/mm²)
1	.134	0.024	4.747	0.081	
2	1.812	0.106	64.134	0.354	
3	7.430	0.391	262.791	1.302	Young Modulus = 263
4	8.484	0.373	300.220	1.245	
5	9.424	0.439	333.321	1.465	Upper Yield = 333
6	8.111	0.757	286.866	2.523	Lower Yield = 287
7	8.168	1.538	288.900	5.127	
8	10.259	2.808	362.821	9.359	
9	11.045	3.979	390.626	13.265	
10	11.534	5.151	407.919	17.171	
11	11.812	6.909	417.753	23.031	
12	11.869	7.764	419.787	25.879	Maximum Stress = 420
13	11.534	9.790	407.919	32.633	
14	10.594	10.791	374.689	35.970	
15	9.511	11.377	336.372	37.923	Fracture Stress = 336

$$A_o = \frac{\pi}{4} d_i^2 = \frac{\pi}{4}(6)^2 = 28.26\,mm^2, \quad A_f = \frac{\pi}{4} d_f^2 = \frac{\pi}{4}(4.3)^2 = 14.51\,mm^2$$

$$Strain\,(\varepsilon) = \frac{l_u - l_o}{l_o} = \frac{42.0 - 30.0}{30.0} = 0.40, \quad \%\ reduction\ in\ area = \frac{A_o - A_f}{A_o} \times 100 = 48.66$$
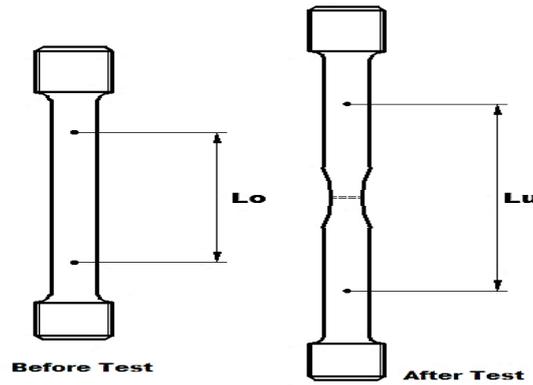
Figure 2. The change in length of a specimen after fracture.

Figure 3. Stress-Strain curve for carbon steel.

Mild Carbon Steel (EN-8): Gauge length (l_0) = 30 mm, gauge diameter (d_0) = 5.8 mm and increased length (l_u) = 34.7 mm reduced diameter (d_f) = 4.7 mm. Data collected during the tensile test are shown in Table 3.

Mild Steel: Gauge length (l_0) = 30 mm, gauge diameter (d_0) = 5.7 mm and increased length (l_u) = 34.0 mm reduced diameter (d_f) = 4.5 mm. Data collected during the tensile test are shown in Table 4.

Hardness

The hardness of the steel specimen is indicated by the depth of penetration of the steel ball indenter on the specimen. The hardness of material imparts the most important properties for determining the strength and resistance to wear and scratching of the surface of the material. The hardness of a material can be defined as the ability of a material to resist indentation or deformation marked on the surface with an indenter under load. The Rockwell hardness of materials was determined using steel ball of 1/16″ diameter and 100 Kgf applied load in scale B. The hardness value was displayed directly on the LCD screen of the universal hardness machine. The Rockwell hardness was

measured on the surface at five different locations and then the values were averaged and noted for each specimen. The hardness of carbon steel was 68.8 HRB, EN 8 steel was 88.5 HRB, and mild steel was 84.18 HRB. The hardness of steel alloys varied due to the presence of Sn, Fe, and Zn content.

Table 3. Tensile test result for EN 8 steel material.

S. No.	Load P (N)	Elongation e (mm)	Stress $\sigma = \dfrac{P}{A_0}(N/mm^2)$	% Elongation $EPS = \dfrac{e}{l_0} \times 100$	Yield Stress, Maximum load, Break point. (N/mm²)
1	0.211	0.024	7.460	0.081	
2	3.288	0.122	116.306	0.407	
3	6.523	0.203	246.989	0.678	
4	11.217	0.415	396.729	1.383	
5	15.177	0.562	536.772	1.872	Young Modulus = 537
6	17.948	0.684	634.767	2.279	Yield Stress = 635
7	21.179	0.928	749.039	3.092	
8	22.339	1.123	790.068	3.743	
9	24.247	1.685	857.546	5.615	
10	24.851	2.100	878.908	6.999	
11	24.946	2.539	882.299	8.464	Maximum Stress = 882
12	24.170	2.979	854.833	9.928	
13	22.492	3.760	795.493	12.533	
14	20.594	4.175	728.355	13.916	Fracture Stress = 728

$$A_o = \frac{\pi}{4}d_i^2 = \frac{\pi}{4}(5.8)^2 = 26.41\,mm^2, \quad A_f = \frac{\pi}{4}d_f^2 = \frac{\pi}{4}(4.7)^2 = 17.34\,mm^2$$

$$Strain\,(\varepsilon) = \frac{l_u - l_o}{l_o} = \frac{37.3 - 30.0}{30.0} = 0.2433, \quad \%\,reduction\,in\,area = \frac{A_o - A_f}{A_o} \times 100 = 34.34$$

Table 4. Tensile Test result for mild steel material.

S. No.	Load P (N)	Elongation e (mm)	Stress $\sigma = \dfrac{P}{A_0}(N/mm^2)$	% Elongation $EPS = \dfrac{e}{l_0} \times 100$	Stress at Yield Point, Maximum load, Break point. (N/mm²)
1	1.467	0.000	51.880	0.000	
2	5.906	0.000	208.876	0.000	
3	15.532	0.000	549.318	0.000	Young Modulus = 549
4	17.315	0.000	612.387	0.000	Upper Yield Stress = 612
5	18.331	0.000	648.331	0.000	
6	18.839	0.000	666.302	0.000	Maximum Stress = 666
7	18.360	0.000	649.348	0.000	
8	10.805	0.049	382.149	0.163	Lower Yield Stress = 382
9	17.353	0.195	613.744	0.651	
10	17.219	0.342	608.997	1.139	
11	15.551	1.025	549.996	3.418	
12	14.266	1.440	504.558	4.801	Fracture Stress = 504

$$A_o = \frac{\pi}{4}d_i^2 = \frac{\pi}{4}(5.7)^2 = 25.52\,mm^2, \quad A_f = \frac{\pi}{4}d_f^2 = \frac{\pi}{4}(4.5)^2 = 15.90\,mm^2$$

$$Strain\,(\varepsilon) = \frac{l_u - l_o}{l_o} = \frac{34.0 - 30.0}{30.0} = 0.1333, \quad \%\,reduction\,in\,area = \frac{A_o - A_f}{A_o} \times 100 = 36.70$$

Impact Test

The impact strength is the measure of the energy absorbed by the standard specimen when it fails while being struck with a hammer. The impact strength of a material can also be defined as equal to the work performed in breaking a specimen during impact test and also related to the toughness of the material. The toughness of the material is to absorb energy during the plastic deformation when subjected to suddenly applied loads. Due to small plastic deformation before failure, the brittle material has low toughness, whereas ductile material has more resistance to suddenly applied load as it can absorb considerable energy before failure. The impact test is normally used to find the safe condition of structural members during industrial and building applications. The specimen with the notch is tested in impact test so that the specimen fails at the notch under a single blow of hammer and at less energy compared to without notch specimen. The energy required to break the specimen is a measure of impact strength. The impact strength of carbon steel, EN 8 steel, and mild steel alloys was tested on pendulum impact testing machine with capacity 150 J and can be increased to 300 J at room temperature. Each specimen is a square rod $10\,mm \times 10\,mm \times 55\,mm$ length with a V-notch of 27.5 mm from one end. The depth of notch was 2 mm and internal angle of V was 45° with a root radius of 0.25 mm and kept on the anvil to support the test. The energy absorbed by the specimen during fracturing was computed by the initial energy of the hammer before striking minus the final energy remaining in the hammer after it broke the specimen. The absorbed energy $(E) = m \times g \times (h_1 - h_2)$ joule was displayed in software installed for supporting the test on pendulum impact testing machine to generate data associated with the test, where m is the mass of the hammer, g is the gravitational acceleration, h is the height of the hammer before striking and h_1 is the maximum height after fracturing the specimen.
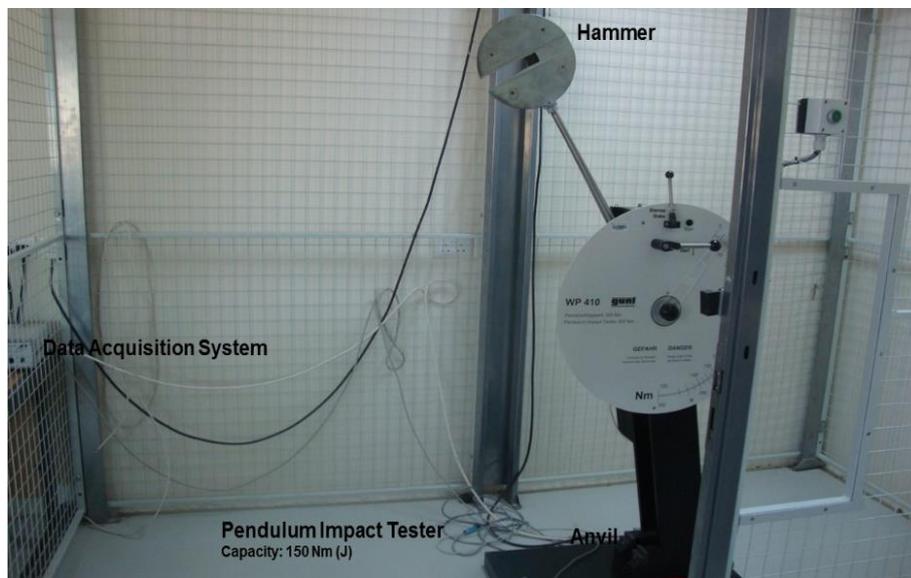
Figure 4. Equipment used for impact test.

The impact strength of the material depends on the lattice type of materials, test temperature, chemical composition of materials, and degree of strain hardening. Figure 4 shows the experimental setup used during the experiment to find the impact strength and finally the fracture surface of the specimen microstructure was observed using an inverted microscope. From the experimental observation, it was observed that the impact strength

of carbon steel was 36.50 J/cm^2, whereas that of EN8 steel was 51.75 J/cm^2 and mild steel was 125 J/cm^2.

RESULTS AND DISCUSSION

The chemical compositions of three steel materials, their mechanical properties after the experimental performance on standard specimen and microstructure of the fracture surface were studied. The results of the analysis are discussed in the following sections.

Metallographic Analyses

The microstructure of steel alloys has more influence on the steel mechanical properties. After the tensile and impact tests, the fractured specimens were neatly cleaned and abraded with SiC paper, polished with 1-µm Al_2O_3 powder, washed with distilled water, and finally etched with 5-10% natal solution for microscopic observation. The fracture surfaces were examined using an inverted microscope provided with internal ISO camera and power supply of 6V/30W halogen bulbs. The camera captured the image while window graphically displayed the frequency distribution of colour values in line view. Figure 5 shows the microstructure of fracture surface after tensile test of carbon steel alloys, EN-8 steel alloys, and mild steel alloys. The microstructure was observed by an inverted microscope of the specimen after fracture and the iron dendrites were identified surrounded by carbon and manganese alloys in grey phase. Figure 6 shows the microstructure of fracture surface after impact test of carbon steel alloys, EN-8 steel alloys, and mild steel alloys.
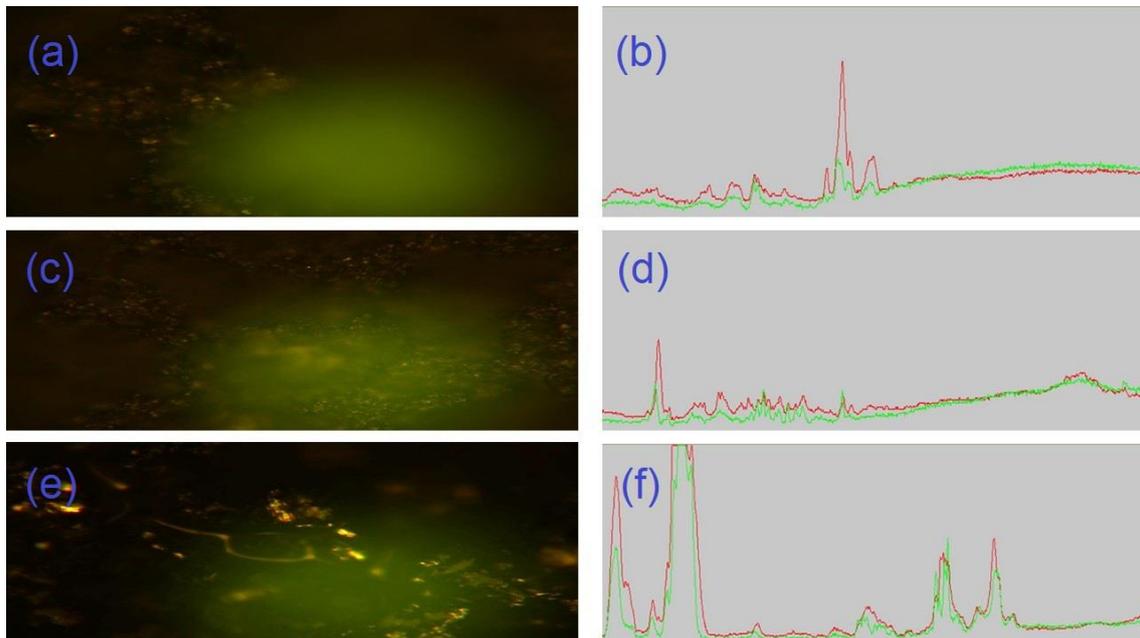
Figure 5. Typical microstructure of steel alloys after tensile test at Mag. 20X: (a) shows the microstructure of carbon steel, (b) shows the colour value variation in a frequency line, (c) shows the microstructure of EN 8, (d) shows the colour value variation in a frequency line, (e) shows the microstructure of mild steel, and (f) shows the colour value variation in a line.
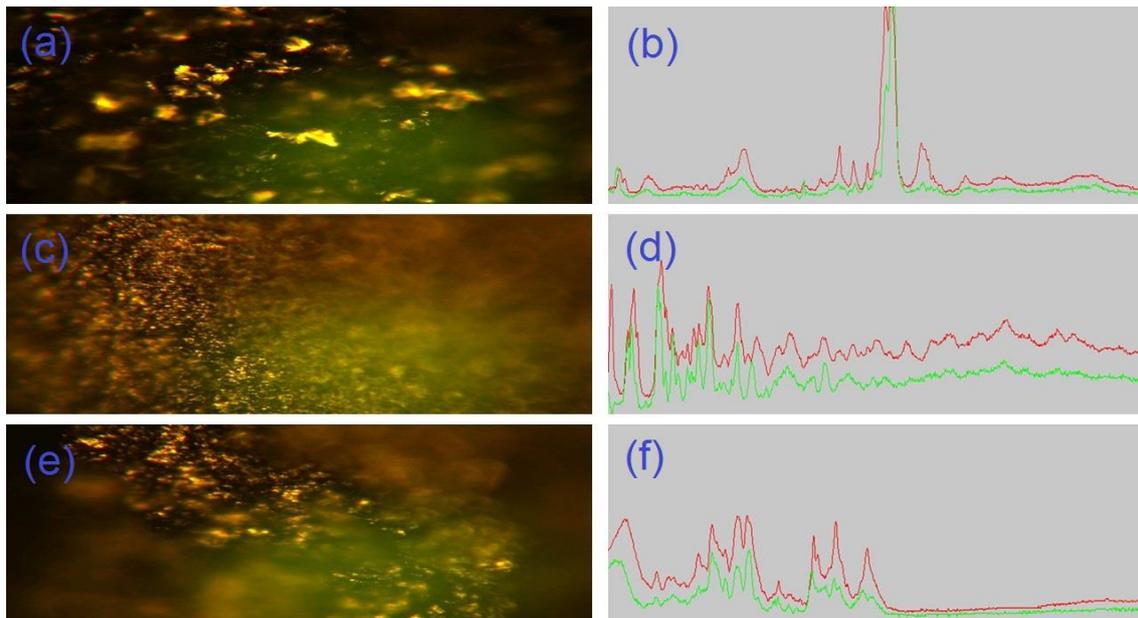
Figure 6. Typical microstructure of steel alloys after impact test at Mag. 20X: (a) shows the microstructure of carbon steel, (b) shows the colour value variation in a frequency line, (c) shows the microstructure of EN 8, (d) shows the colour value variation in a line, (e) shows the microstructure of mild steel and (f) shows the colour value variation in a frequency line.

Tensile Properties

Chen et al. [32] presented the tensile properties and microstructural behaviour of Hadfield steel by applying different strain rates during tensile test and found that by the addition of N+Cr tensile strength increased considerably. Xiaoyun [33] investigated the mechanical properties and anti-corrosion behaviours of Cr and Mn addition to Fe-Mn-C-Al-Cr-N steel have investigated and found that Cr addition increased ultimate tensile strength and yield strength but reduced percentage elongation. Furthermore, increased Cr content improved the corrosion resistance of the annealed steel. The variation of tensile strength and percentage elongation were analysed by experiment on the silicon content varied from 5, 7, 9, 12.5, and 14% in five different aluminium alloys. The research found the significant increase in tensile and yield strengths of the material whereas a decrease in the ductility [34]. The mechanical properties of superplastic materials were investigated on superplastic Al–4·5Mg alloy with different gauge lengths and elongation was found to increase to double when gauge length to width ratio reduced 4 to 1 [35]. The ultimate tensile and yield strengths of steel weld metals decreased but the impact strength of weld metals increased by Ni additions in a controlled manner with respect to Mn . According to Scott et al., high-Mn austenitic steels are mostly used in automotive engineering applications due to its high strength and ductility [36]. Manganese combined with sulphur decreases the threat of solidification cracking [37]. The addition of chromium stabilises ferrite and increases tensile strength and hardness of steel as a solid solution strengthener but reduces toughness [15]. This paper investigated the microstructural behaviour and mechanical properties of three high strength low alloy sheets of steel used for armoured vehicle and found that the tensile strength of RHA had the highest value compared to other two AR500 and AISI 4340 sheets of steel [38]. The toughness of steel material depends on its chemical composition and microstructure [39]. The investigation of microstructure and mechanical properties of stainless steels having 0.004 wt %C to 0.034 wt %C was conducted and the martensitic texture was found to be

influenced by carbon content [40]. The hardness and strength of the stainless steel increased by an increase in carbon content but at the same time decreased elongation and toughness[41]. The paper investigated the mechanical properties and microstructural behaviour by precipitation hardening effect on Al-Cu-Zn alloys and found that precipitation hardening increased the mechanical properties of aluminium alloys widely used in automobiles [42].

The tensile properties of three steel alloys at a strain rate of 1.3×10^{-4} s^{-1} on UTM were tested and data generated for each alloy as shown in Tables 2, 3, and 4 for carbon, EN 8, and mild steels, respectively. The result of the tensile test is shown in Figure 3, where the plotted graph of stress-strain curves in software supports the UTM test while the generated data for carbon steel material are shown in Table 2. From the stress-strain graph, it was observed that carbon steel has Young's Modulus = 267 N/mm^2, upper yield stress = 333 N/mm^2, lower yield stress = 287 N/mm^2, maximum Stress = 420 N/mm^2, and fracture Stress = 336 N/mm^2. Like carbon steel, generated data for EN 8 and mild steel alloys are shown in Tables 3 and 4, respectively. Based on the test generated data shown in Tables 2-4, stress via elongation graph was plotted and is shown in Figure 7 for carbon, EN-8, and mild steel alloys. From Figure 7, it can be observed that the carbon steel has the upper/lower yield stress as 333/287 N/mm^2, maximum stress as 420 N/mm^2, and the fracture stress as 336 N/mm^2. Similarly, for EN 8 steel, the yield stress was 635 N/mm^2, maximum stress = 882 N/mm^2 and fracture stress was 728 N/mm^2, whereas for mild steel the upper yield stress was 612 N/mm^2, lower yield stress 382 N/mm^2, maximum Stress 666 N/mm^2, and fracture stress 504 N/mm^2. From Figure 7, it was resolved that carbon steel alloy has high ductility, medium tensile strength, and hardness compared to EN 8 and mild steel alloys. Finally, Figure 8 shows that the stress-percentage elongation graph in software supports the UTM test and easy to observe the comparative test result mentioned above.
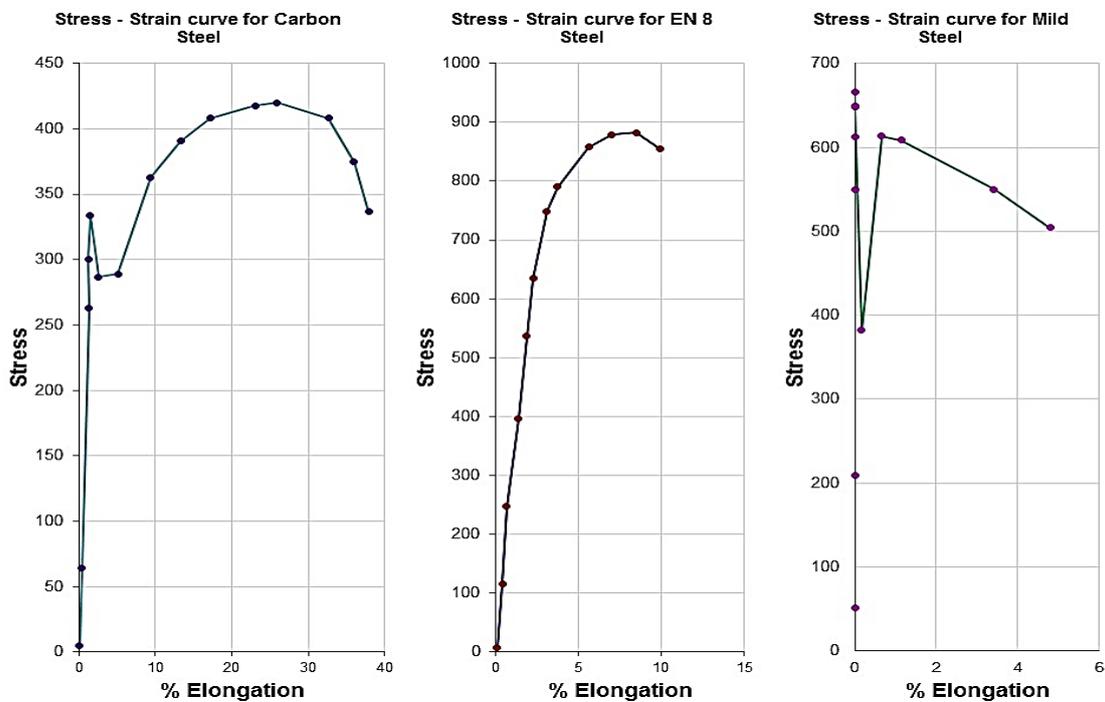
Figure 7. Typical stress–strain curves for carbon, EN 8, and mild steel alloys at a strain rate of 1.3×10^{-4} s^{-1}
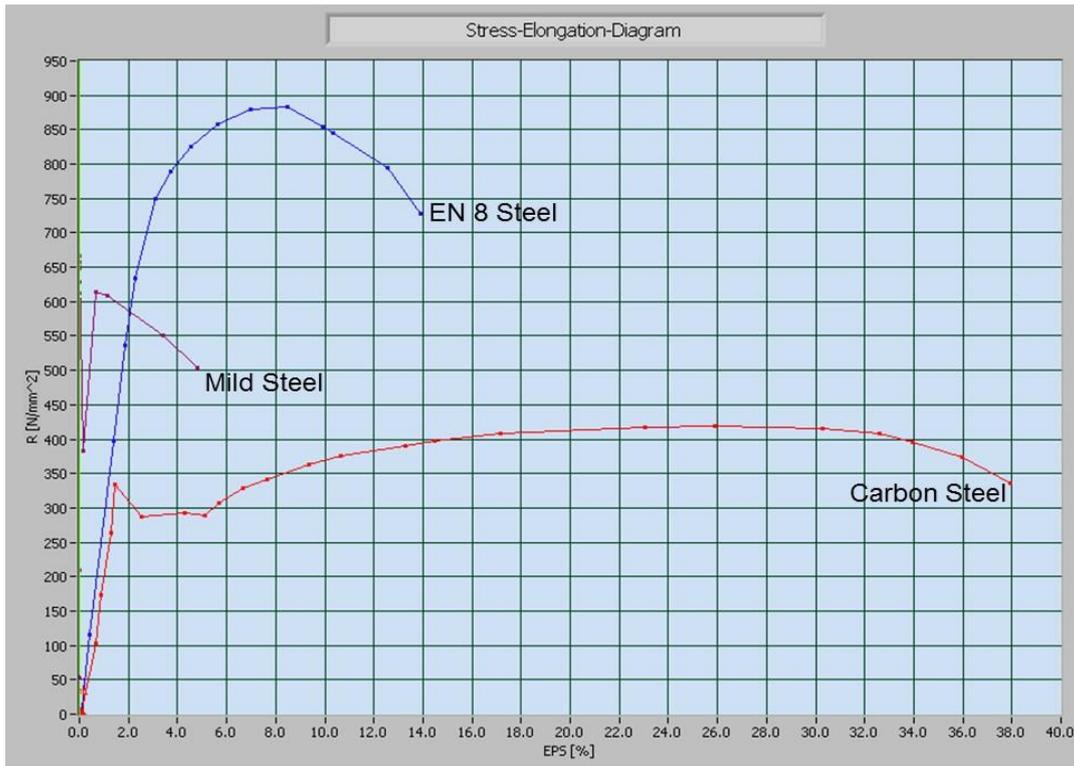
Figure 8. Comparative study of stress-elongation graph for three steel alloys.

Table 5. Mechanical properties of three steel alloys after all tests at room temperature.

Material Properties		Carbon Steel	EN-8 Steel	Mild Steel
Young modulus	N/mm^2	263	537	549
Yield stress	N/mm^2	333/287	635/0	612/0
Ultimate tensile strength	N/mm^2	420	882	743
Tensile Strength at Fracture	N/mm^2	336	728	505
Total Elongation	%	38	14	5
Rockwell Hardness	HRB	68.8	88.5	84.18
Impact Strength	J/cm^2	36.50	51.75	282.26

From the stress-strain graph plotted in Figure 8, it can be observed that EN 8 steel alloy has high yield stress and tensile strength but lower ductility while mild steel alloy has a medium yield stress and tensile strength but medium ductility compared to carbon steel alloy. The addition of Cr and Si to iron forms a solid solution, which significantly increased the strength and corrosion resistance [32 – 34]. Specimen dimensions also influence the tensile strength and ductility of the material. As the gauge length increased, it reduced the effect of localised deformation at necking on total elongation; i.e., by increasing the gauge length percentage elongation of the specimen is further reduced [35]. The strain-hardening capacity of material also has impacts on the percentage elongation. During the test, the strain rate increased and significantly increased the flow stress. The addition of manganese gave strengthening effects by solid solution hardening and grain refinement during heating and cooling of the specimen by lowering the austenite to ferrite transformation temperature [33]. The toughness of steel was further increased by the grain

refinement and also by the addition of nickel. The impact of Cr addition in two types of Co-Ni steels, one containing only W while others containing W and Cr, were studied and cooperation yield strength and yield ratio (YS/UTS) were identified to decrease by the addition of Cr [42]. Table 5 shows the comparative observations of mechanical properties after the test results.

CONCLUSIONS

In this research, the mechanical properties and microstructural behaviour of three steel alloys were investigated using tensile, impact, and Rockwell hardness tests. The analysis of the result was conducted based on the variation and effect of the chemical composition of the alloying elements added to the steel on the mechanical behaviour. The experimental result showed that EN 8 steel had the highest ultimate tensile strength of 882 N/mm^2 followed by the mild steel of 666 N/mm^2 and carbon steel has the lowest value 420 N/mm^2. The percentage elongation of the steel alloys was compared as the highest value of elongation for carbon steel at 38% followed by EN 8 steel at 13.8% and the mild steel had the lowest elongation value at 4.8%. The yield and ultimate tensile strengths of EN 8 steel were the highest due to more Si content in it compared to mild and carbon steels whereas percentage elongation decreased in EN 8 steel compared to carbon steel as more Si addition increased tensile strength but reduced ductility. Similarly, the composition of reduced Mn with increased Ni content increased the impact strength of mild steel compared to EN 8 steel. The increase in Mn content more than 0.23% reduced the elongation capacity of the EN 8 steel alloys and mild steel. The increased percentage weight content of Cr significantly improved tensile and yield strengths and reduced elongation of steel alloys. Further microstructural studies of steel alloys were investigated for different composition of alloying elements using an inverted microscope of the fracture surface of the specimens.

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