Available online at www.ijapie.org

International Journal of Advanced Production and Industrial Engineering

IJAPIE-SI-MM 502 (2017) 06–17

Special Issue on

MATERIALS & MANUFACTURING

Effect of Varying Chemical Composition on Mechanical Behaviour of Ferrous Cast Product

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Abstract : *In this paper, focus is to study effect of varying chemical composition on mechanical behavior of ferrous cast product. Ferrous materials occupy a significant position among engineering materials because of their chemical, physical and mechanical properties. In engineering applications, a suitable combination of these properties is required. Mechanical properties have major role among the combination of chemical, physical and mechanical properties. Steel drives its mechanical properties from a combination of chemical composition, heat treatment and manufacturing processes. Although the major constituent of steel is iron yet the addition of very small quantities of alloy elements can have a marked effect upon the properties of steel. The strength of steel can be increased by the addition of alloy elements. However these alloy elements addition can also adversely affect other properties such as ductility and weld ability. Hence, the chemical composition for each steel balanced carefully and tested to ensure that the appropriate properties are achieved. Five elements, manganese, chromium, nickel, carbon and molybdenum are selected to find their effect on mechanical behavior of alloy steel. To find the effect of any one element on mechanical properties of alloy steel, we had cast a test piece with desired chemical composition and "chemical composition v/s mechanical properties" tests were carried out. Similarly for the second test, a second test piece is casted with chemical composition slightly changing the alloy element and their effects have been found. It was observed that there is significant improvement in the mechanical properties.*

Keywords: *Alloy element, Chemical composition, Mechanical properties, ferrous material.*

INTRODUCTION

Historically development and advancement of society have been intimately tied to ability of its members to produce and manipulate materials to meet their day to day needs. In fact, early civilizations have been designated by the level of their material development (Stone Age, Bronze Age, and Iron Age).

Furthermore, it was discovered that properties of a material can be altered by heat treatment and by the alloying of other substances. It is useful to sub divide the discipline of material science and engineering into material science and material engineering sub disciplines. Material science involves investigating the relationship that exists between structures and properties of material although material engineering is on the basis of these structure –property co-relations [10]. All important properties of solid material are grouped into following six categories: Mechanical, Electrical, Thermal, Magnetic, Optical, Deteriorative

Many times a material problem is one of selecting the right material from the many thousands that are available.There are several factors on which the final decision is normally based first of which is to characterized service condition than we find the properties which required for material.A second selection consideration is any deterioration of material properties that may occur during service operation. Finally, probably the important consideration is that of economics thatwhat will the product cost.

MATERIAL CLASSIFICATION

Most Engineering materials are classed into any one of the following

Metals – Ferrous and Non – Ferrous: these are composed of one or more metallic elements such as Iron, Aluminum, Copper, Titanium,Gold and Nickel and also nonmetallic elements for example Carbon, Nitrogen and Oxygen. [11] Metals generally possess the characteristics such as luster, hardness, low specific heat, plasticity, formability, good thermal and electrical conductivity, relative high meltingpoint, Strength, ,Malleability, Opaqueness, Stiffness, Rigidity and Formability, Machinability, Weldability, Castability, Dimensional stability. Commonly employed metals areIron, Aluminum, Copper, Zinc, Magnesium etc.

Ceramic Material: These are consist of oxides, nitrides, carbides, silicates or borides of various metals. These are many inorganic, non-metallic solids processed.These materials are rock or clay minerals materials. These Materials contain compounds of metallic and non-metallic elements such as MgO, SiO_2, SiC, $BaTiO_3$, glassesetc. such compounds contain both ionic and covalent bonds. These materials are generally have High temperature strength, Hardness, Rock – like appearance, Corrosion resistance, Resistance to high temperatures, Good Insulation, Opaqueness and Brittleness

Organic materials: are polymeric material composed of carbon compounds. Polymers are solids composed of long molecular chains. Countless organic materials are natural and synthetic or manufactured and based chemically on carbon. These have Poor resistance to temperature, Not dimensionally stable, Poor conductors of heat and electricity, Ductile, Light weight, Combustible. Adhesives, Plastics, Paper, Explosives, Fuels, Woods, Textiles, Rubber and Paints are examples of Organic materials.

Polymer include plastic and rubber materials. Many of them are organic compounds that are chemically based on hydrogen, carbon, and other non-metallic elements: furthermore, they have very large molecular structures. Polymers materials typically have low densities and extremely flexible.

Composites: These materials consist of more than one material type. Fiber – glass is a familiar example, in which glass fibers are embedded within a polymeric material. A composite is designed to display a combination of the best characteristics of each of the components materials. Fiberglass acquires strength from the glass and flexibility from the polymer.

Semiconductors: These have electrical properties that are intermediate between the electrical conductors and insulators. Furthermore, the electrical characteristics of these materials are extremely sensitive to the presence of minute concentrations of impurity atoms, whose concentrations may be controlled over very small special regions. These have made possible the advent of integrated circuitry that has totally revolutionized the electronics and computer industries.

Engineering requirement of a material mean as what is expected from the material so that the same can be successfully used for making engineering components such crankshaft, spanner etc. When an engineer thinks of deciding and fabricating an engineering part, he goes on to search of that material which possesses such properties as will permit the components part to perform its functions successfully while in use. For example, one may select high speed steel for making a milling cutter or a power hack saw blade. Materials are required for Service, Fabrication and Economic.

Ferrous Materials

Due to their extensive use,ferrous materials are very important in the society. Widespread the broad use of alloy is accounted by thefactors that Iron containing compounds exists in major quantity in the earth's crust. By using relatively economical extraction refining, alloying and fabrication techniques metallic irons and alloy may be produced. Ferrous materials have a wide range of mechanical and physical properties. Susceptibility to the corrosion is main disadvantage of ferrous materials.

Pig iron: is originated in the early days by iron ore reduction. The method of pig casting in sand beds has been largely superseded by the pig casting machines. In cupola Furnace pig iron is refined then various grades of cast iron are produced. From pig iron various steel making process are used such as Bessemer, open–hearth etc.

Wrought Iron: Mechanical Mixture of very pure iron and silicate slag is called wrought iron. It is a ferrous material. Uses of wrought iron are in building construction, public works, industrial, road and marine and others such as gas collection hoods, handling equipment, cooling tower and spray pond piping. Manufacturing of wrought iron is done by pudding process and ton's process.

Grey Cast Iron: Basically it is an alloy of carbon and silicon with iron. It is readily casted into a desired shape in sand mold. It contains 2.5-3.8% C, 1.1-2.8%Si, 0.4-1%Mn, 0.15% P and 0.10% S. It has high fluidity hence, it can be casted into a complex shapes and thin sections.

Malleable Cast Iron: It can be hammered and rolled to obtain different shapes. Malleable cast iron has 2-3%C, 0.3-1.3% Si, 0.2-0.6%Mn, approx. 0.15%P and 0.10 % S. It is used for manufacturing of Automotive crank shaft, sprocket, rear axle housing, Gear case, Automotive industryrail road, Agricultural implements, Electrical line hardware, Conveyor chain links and truck axle assembly parts.

Nodular cast iron: possesses damping capacity intermediate between cast iron and steel. It possesses excellent cast ability and wear resistance.Ductile cast iron or nodular cast iron contains 3.2%-4.2%C,1.1-3.5%Si, 0.3-0.8% Mn,approx. 0.08% P and 0.02% S. It is used for manufacturing of Pipes, pumps and compressors, valves and fittings, pumps and compressors, construction machinery, parts of tractors, power transmission equipment, internal combustion engines parts, Paper industries machinery.

STEELS : An alloy of iron and carbon is called steel.

Plain carbon Steel: An alloy of iron and carbon is plain carbon steel. It is different from cast iron as regards the percentage of carbon. Carbon steel contains from 0.10% - 1.50 % carbon whereas cast iron contains from 1.82 %– 4.82 %, carbon classification of carbon steel may be as low carbon steel , medium carbon steel and high carbon steel .

Low carbon steel or Mild steel: may be classified as Dead mild steel has carbon percentage from 0.05 - 0.15 %. It has tensile strength approx. 390 N/mm^2 and hardness ; approx.115 BHN. and Mild steel Mild steel containing 0.15 % -0.20% carbon, has tensile strength about 420N/mm^2 and hardness about 125 BHN.Mild steel containing 0.20 % - 0.30% carbon, has tensile strength about 555MPa and hardness about 140 BHN.

Medium Carbon Steel: It contains 0.30-0.45% carbon. The steel having 0.30-0.45% carbon has tensile strength of about 750N/mm^2.They are used for making small and medium forgings axels, brake levers, wires and rods, connecting rods, spring clips, gear shafts. Steel containing 0.50 -0.55% Carbon has tensile strength approx.1000 N/mm^2 and are used for parts subjective to heavy shocks such as crank shafts, crank pins, railway coach axles and shafts.

High carbon steel: has Carbon 0.60 - 1.50 %.Steel Containing 0.6 - 0.75% carbon has tensile strength of 1230 N/mm^2 and hardness of 400-450 BHN and are used for making die blocks, clutch discs, plate punch and forging die, cushion rings, valve springs, etc.Containing 0.75 % – 0.8% carbon, tensile strength approx. 1400 N/mm^2 and hardness approx. 450-500 BHN. These steels are used for making automobile clutch disc, shear blades, cold chisel, wrench, jaw, pneumatic drill bits, and wheels for railway services trains. Containing 0.8 % -0.9% carbon, High Carbon Steel has a tensile strength approx. 660 N/mm^2 and hardness 550 BHN. These steels are used for manufacturing shear blades, pins,spring, punch and keys etc. Containing 1 % - 1.1% carbon, high carbon steel are applicable for mandrels, railway springs, machine tools. Containing 1.1 % – 1.2% carbon, high carbon steel are applicable for knives, twist drills and taps. Containing 1.2 % - 1.3% carbon, high carbon steel are applicable for reamers, files, metals cutting tools etc. Containing 1.3 % - 1.5% carbon, high carbon steel are applicable for metal cutting saws, wire drawing dies, tools for turning chilled iron etc.

Alloy Steel: is considered to be alloy steel when the maximum of the range given for the content of alloying elements exceeds one or more of the following limits: Mn1.65%, Si 0.60%, Cu0.60% Or in which a definite range or a definite maximum quantity of any of the following elements is specified or required within the recognized filed of constructional alloy steels: Al, B, Cr, up to 3.99%, Co, Mo, Ni, Ti, W, V, or any other alloying elements added to obtain a desired alloying effects.

OBJECTIVE DESCRIPTION

In this paper, the problem is to find the effect of varying chemical composition on mechanical behavior of ferrous cast product.

To solve the problem, selected five important alloy element for composition of alloy steel from the available process and taken practical data for the :

- Effect of manganese percentage change in casting of steel while rest elements of composition remain same during process.
- Effect of chromium percentage change in casting of steel while rest elements of composition remain same during process.
- Effect of nickel percentage change in casting of steel while rest elements of composition remain same during process.
- Effect of carbon percentage change in casting of steel while rest elements of composition remain same during process.
- Effect of Molybdenum percentage change in casting of steel while rest elements of composition remain same during process.

The practical data taken and analyzed.

The above data had been taken after close observation on casting processes of steel castings in manufacturing unit of defense. Data taken from running process and used to solve the problem. Hence description of process is necessary which is given below in fig 1.

MATERIAL SELECTION

Since Observation has been taken from a running Process of a defense Manufacturing Unit, Hence, material is taken according to design and strength as per customer's requirement. Main customers are Air force, Navy and Army. According to the requirement, a NC: TC (notification criteria for test certificate)has been prepared for each product.

NC:TC (notification criterion for test certificate)

PREPARATION

As per requirement NC:TC is made, it is written document which shows chemical composition, heat treatment and all other processing conditions to be followed.

PATTERN MAKING

It is actual replica of cylindrical circular bar which we have casted for various mechanical strength tests.

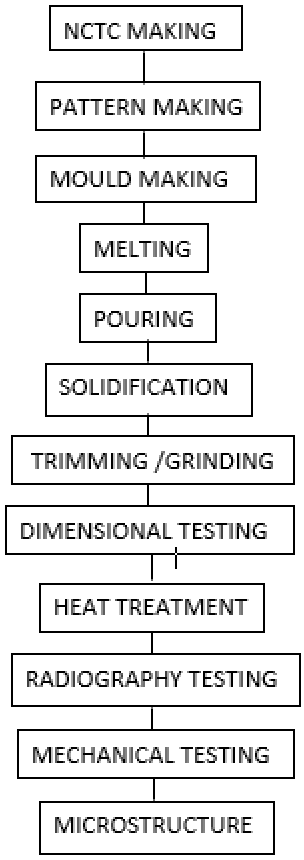

Fig. 1 Shows flow chart of ferrous casting

MANUFACTURING OF MOULD

There are different methods to make the mould for different casting. For heavy casting, for running mass production sand mould are generally used in this manufacturing unit.

Fig. 2 Mould making process [15]

MELTING

Melting is the major factor after the mould preparation, it defines the characteristics of product. There are a number of furnaces available for melting the alloys in foundry such as cupola, rotary furnace, open hearth furnace and pit furnace etc. choice of furnace depends on the amount and type of alloy being melted. For melting of cast iron, a cupola furnace in its various forms is used. It has lower initial cost and lower melting cost. But In this manufacturing unit, electric arc open hearth furnace and induction open hearth furnace are used.

ELECTRIC ARC OPEN HEARTH FURNACE:

Due to heavy steel casting, in this manufacturing unit electric arc open hearth furnace is used. Electric arc open hearth furnace is very suitable for ferrous materials. This furnace draws an electric arc that rapidly heats and melts the charge material. The bowl – shaped bottom of the furnace, called the hearth. It is lined with refractory bricks and granular refractory material. From electric arc to charged metal, the heat is transferred directly. The electric arc hearth furnace has a tilting mechanism allowing it to be forward for material tapping or backward for deslaging.

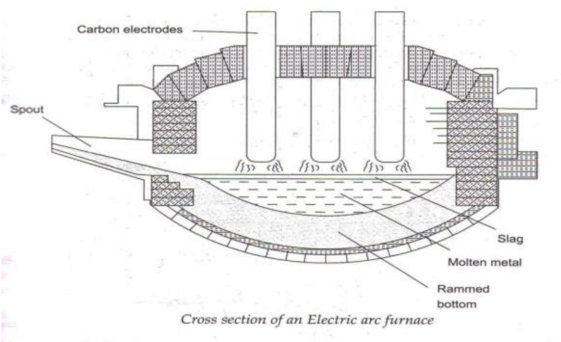

Fig. 3 Electric arc furnace [11]

INDUCTION OPEN HEARTH FURNACE

This furnace is used for all types of material. The main advantage being that the heat source is isolated from the charge, slag and flux get the necessary heat directly from the charge instead of the heat source. In this furnace, high frequencies help in stirring the molten metal and thus help in using the metal swarf. With this furnace, better control of temperature and composition can be achieved. The main advantages of this furnace are: Compact installation, Natural stirring, Higher yield, Faster start up, Cleaner melting

After selecting the furnace, the charge calculation is done and then furnace is charged with metal. Now furnace is started. First of all, slag is taken out from the top of furnace then sample is taken out for spectro. After spectro checking composition of metals is known. According to the metal composition, mixing is done in lower quantity after proper mixing again sample is taken for spectro checking and again mixing is done.In the same manner about four samples are taken then final composition is received.

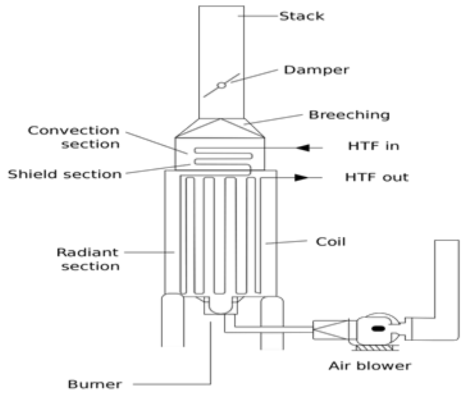

Fig. 4: Furnace [15]

POURING

After melting, pouring is done in mold by the ladle.Molten metal is poured into the mold by ladle. The molten metal from the furnace is tapped into the ladle at requisite interval. There are different sides of ladle depending on the amount of metal. Ladles range between 50 kg to 30 tons.

Fig. 5: Pouring[15]

SOLIDFICATION and COOLING AT ROOM TEMPERATURE / QUENCHING

Solidification is the very important part of process, because it prevents the defect of casting and provides the different beneficial characteristics to casting. According NC: TC (Process Plan) after pouring at requisite time, mold is opened. Casting is cooled at room temperature OR Quenching is done.

Fig.6: Water quenching[15]

TRIMMING / GRINDING

In casting Process due to riser, runner, gate and allowances access material occurs at the casting renewing from mould. Hence, to give proper size and proper dimensions trimming / grinding is required.

Fig. 7 Trimming and grinding[15]

DIMENSIONAL TESTING

After training and grinding, dimensional measuring is done to remove the extra material and to give proper size.

Fig. 8: Dimensional Testing [15]

HEAT TREATMENT

In heat treatment, a define temperature is given and maintained for define interval. Also cooling is done at necessary rate to obtain desired properties associated which change in nature of size and distribution of micro constituents.

RADIOGRAPHY TESTING

The purpose of radiography is to detect the defectswhich affect the mechanical properties as well as other characteristics of materials. Defects detected by the radiography may be- Blow holes, Gas inclusion, Shrinkage, Sand inclusion, Foreign particle inclusion, Cavity Radiography is the technique based upon the exposing the components to short wave length radiation in inform of X-Rays or Gamma Rays. In radiography process, radiography plates are exposed with casting products. These radiography plates (such as negative of photo graphs) are processed and then check in front of illuminator. During checking at illuminator defects are detected.

MECHANICAL TESTING

Castings free from defects detected in radiography are tested mechanically. These tests are such as : Tensile tests, Hardness test, Impact tests, Bend tests, Fatigue test and Creep test.

MICRO STRUCTURE TEST

After checking of mechanical testing, microstructure test is also done.

Fig. 9 Microstructure testing[15]

RESULTS AND DISCUSSIONS

Effect of Manganese in alloy steel : More than 1.65% manganese is considered in alloy steel group. Manganese is added in the range of 1.65 -1.90% to improve the strength, Hardness, Workability, Yield Strength Manganese lowers ductility and weldability. Such an improvement in properties of steel is obtain at almost no extra cost or at marginal increase in cost as manganese is expensive element.

Observation: If base elements of a steel alloy are such as C –0.26 % , Si- 0.43% , S-0.006%, P-0.007% With Chemical Composition given above an observation for change in percentage of Manganese vs YieldStrength has been taken and shown in table 5.1.

Table 1- Manganese vs Yield Strength

SAMPLE NO.	% OF MANGANESE	YEILD STRENGTH
1	1.08	28.55 PSI
2	1.11	28.95 PSI
3	1.23	30.15 PSI
4.	1.276	34.18 PSI
5.	1.329	38.15 PSI

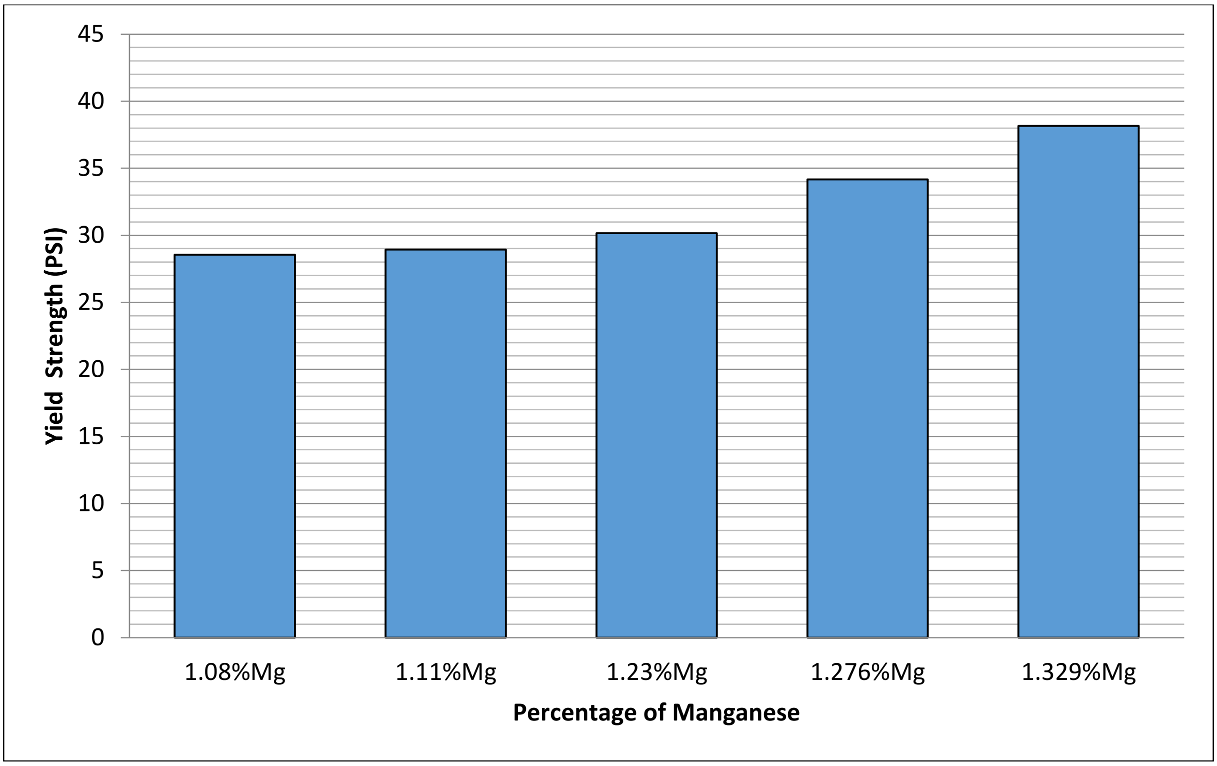

Fig. 10: Manganese vs Yield Strength

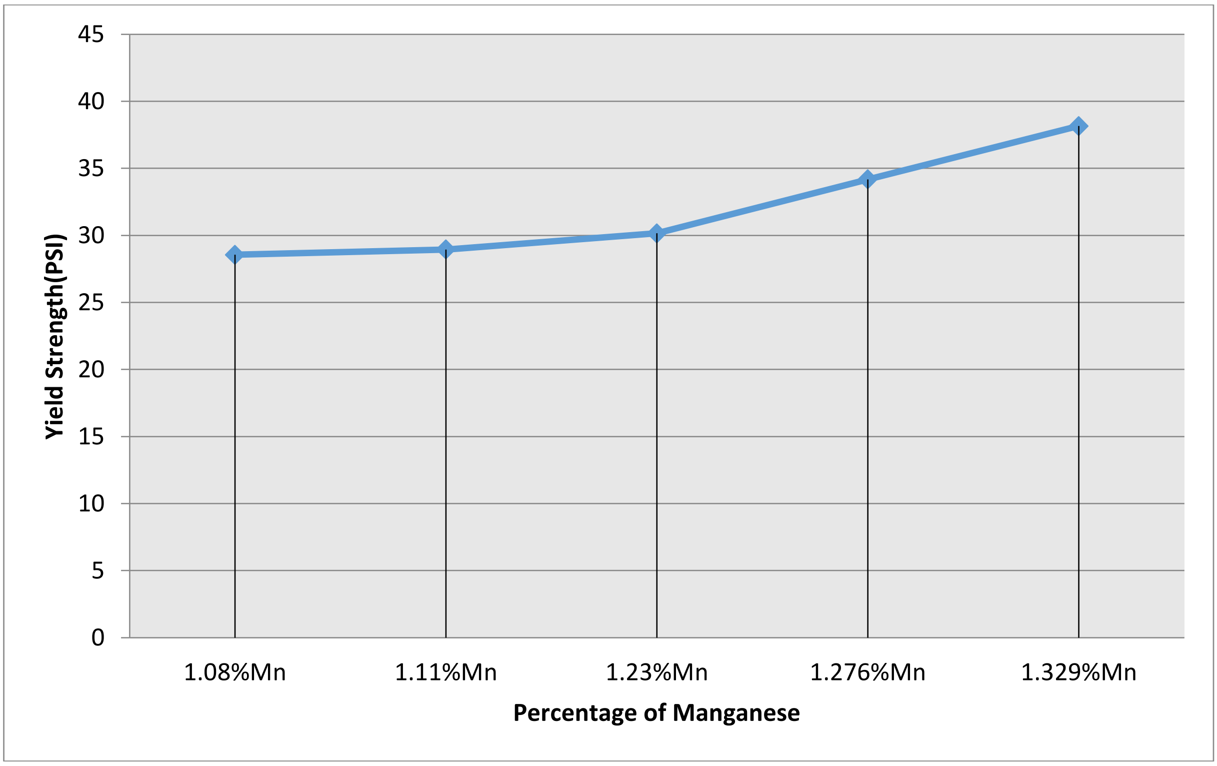

Fig. 11: Manganese vs Yield Strength

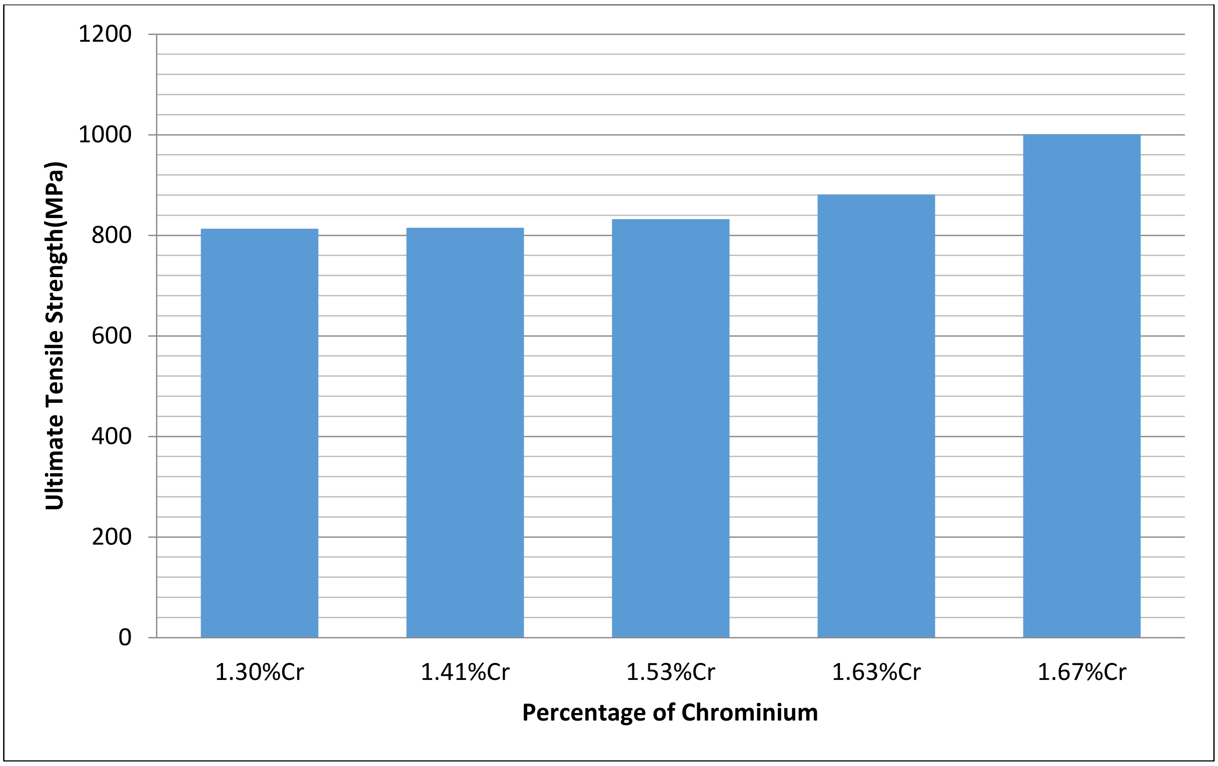

Fig. 12: Chromium vs Ultimate Tensile Strength

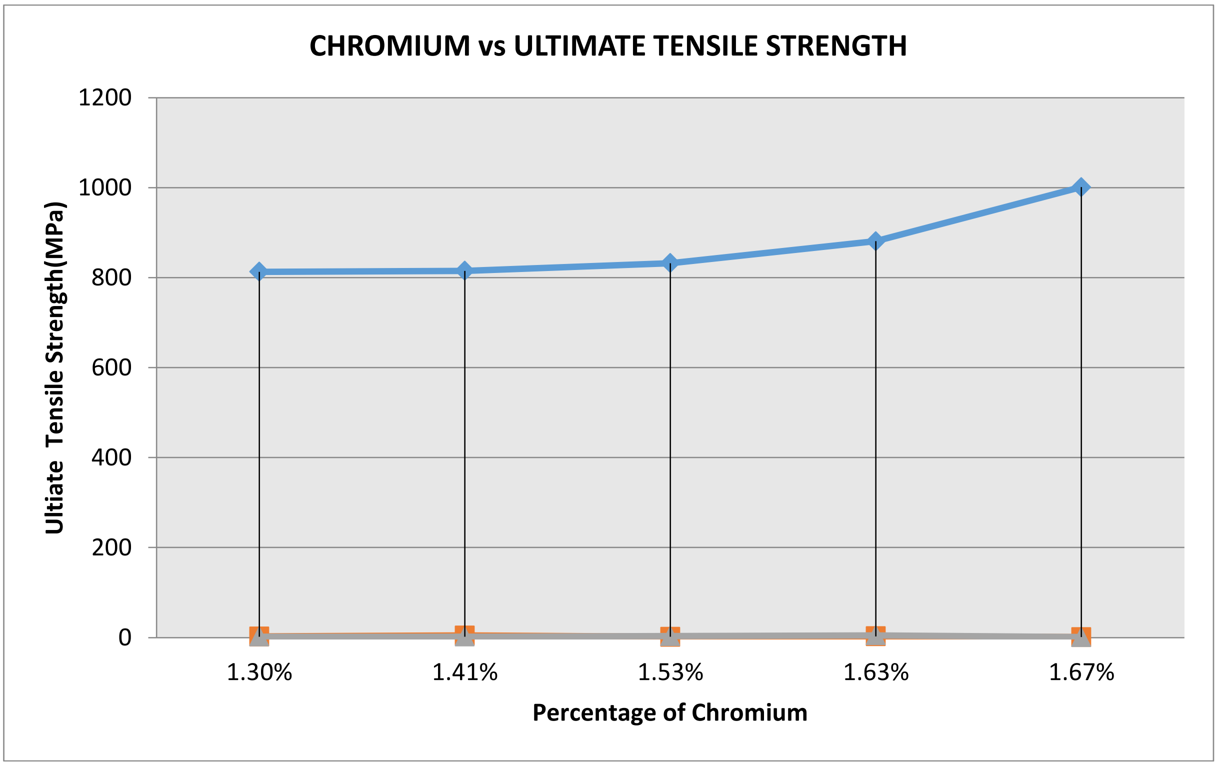

Fig. 13: Chromium vs Ultimate Tensile Strength

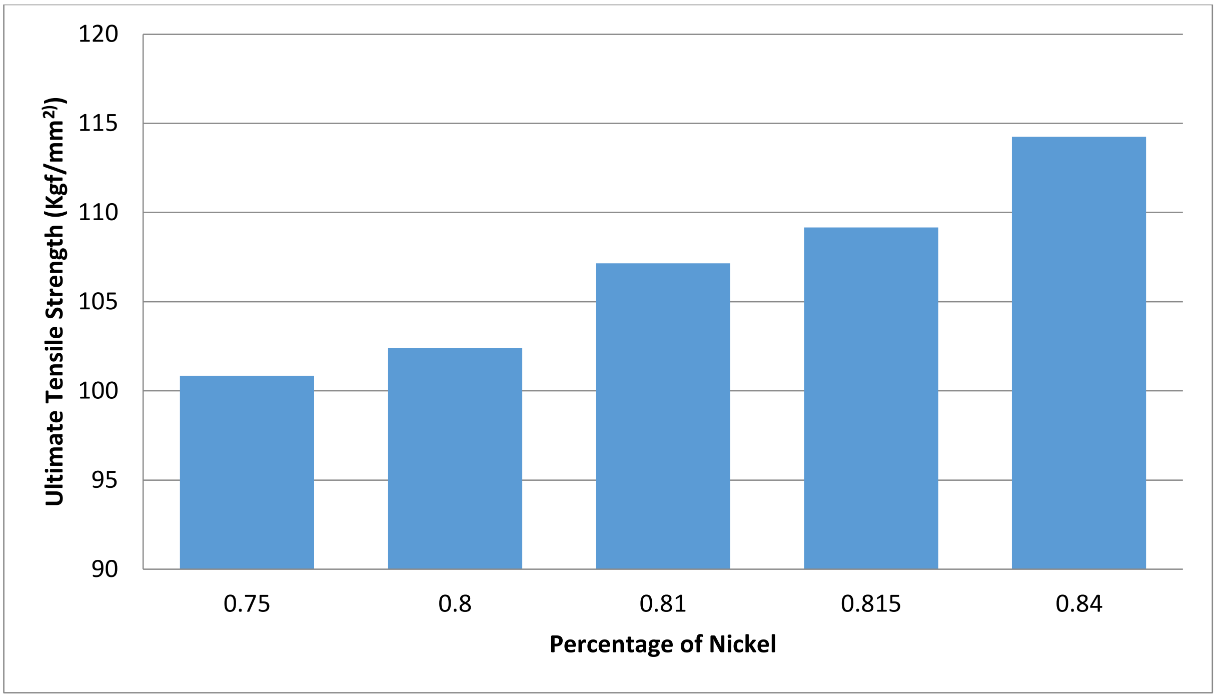

Fig. 14: Nickel vs Ultimate Tensile Strength

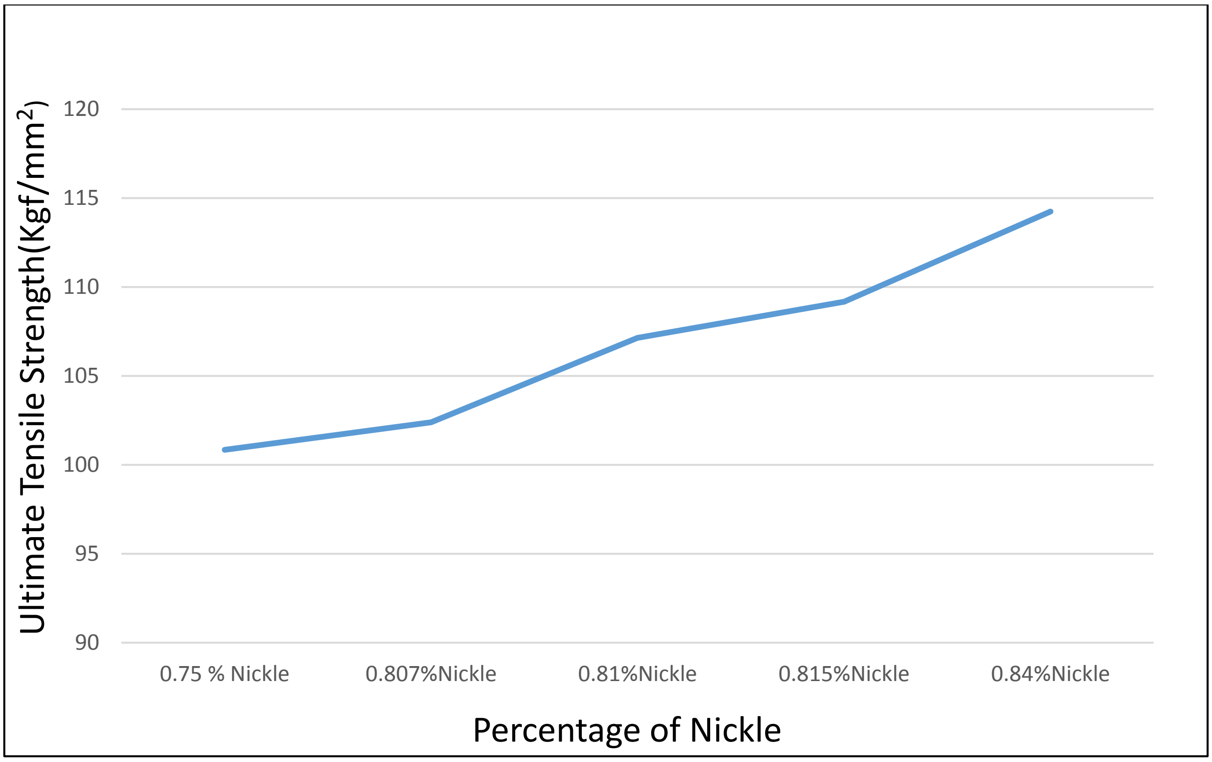

Fig. 15: Nickel vs Ultimate Tensile Strength

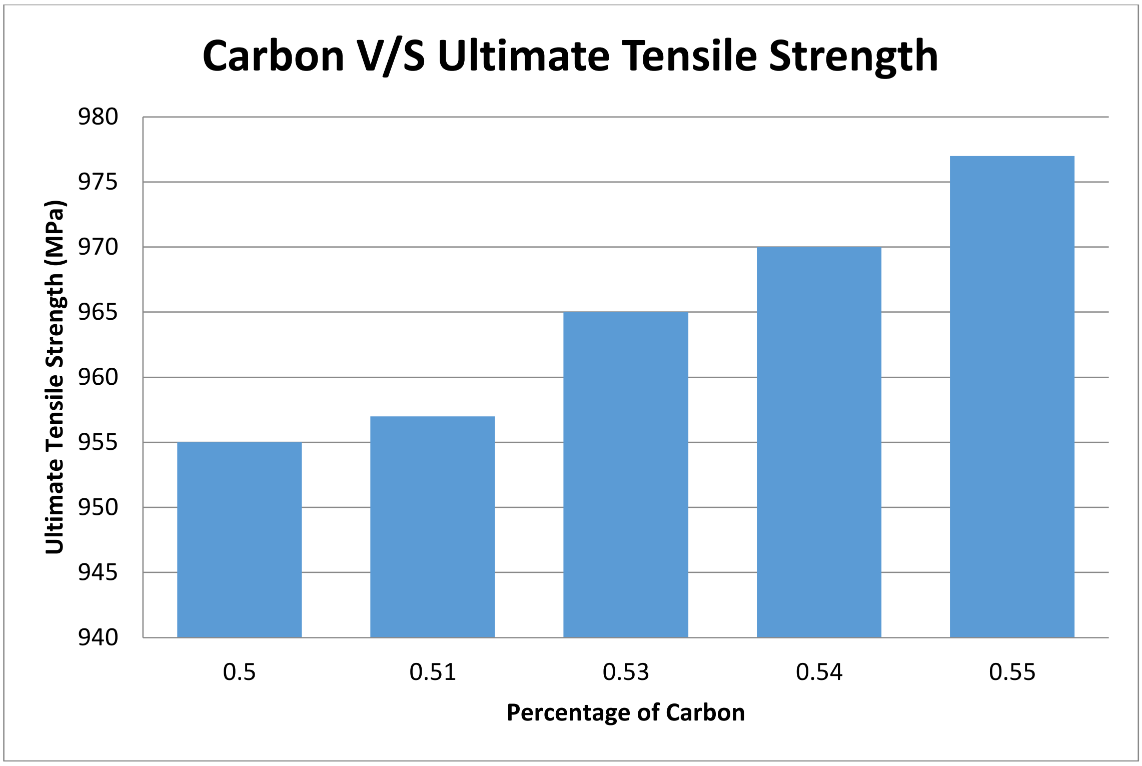

Fig. 16: Carbon vs Ultimate Tensile Strength

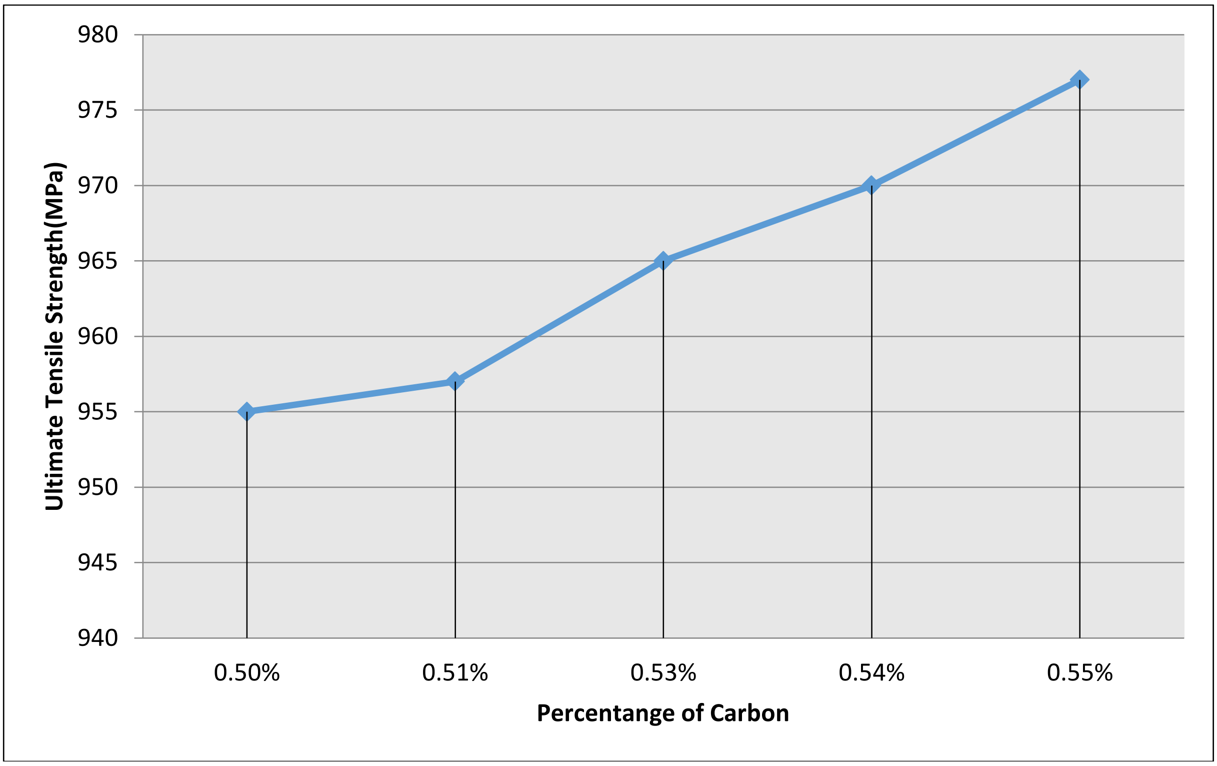

Fig. 17: Carbon vs Ultimate Tensile Strength

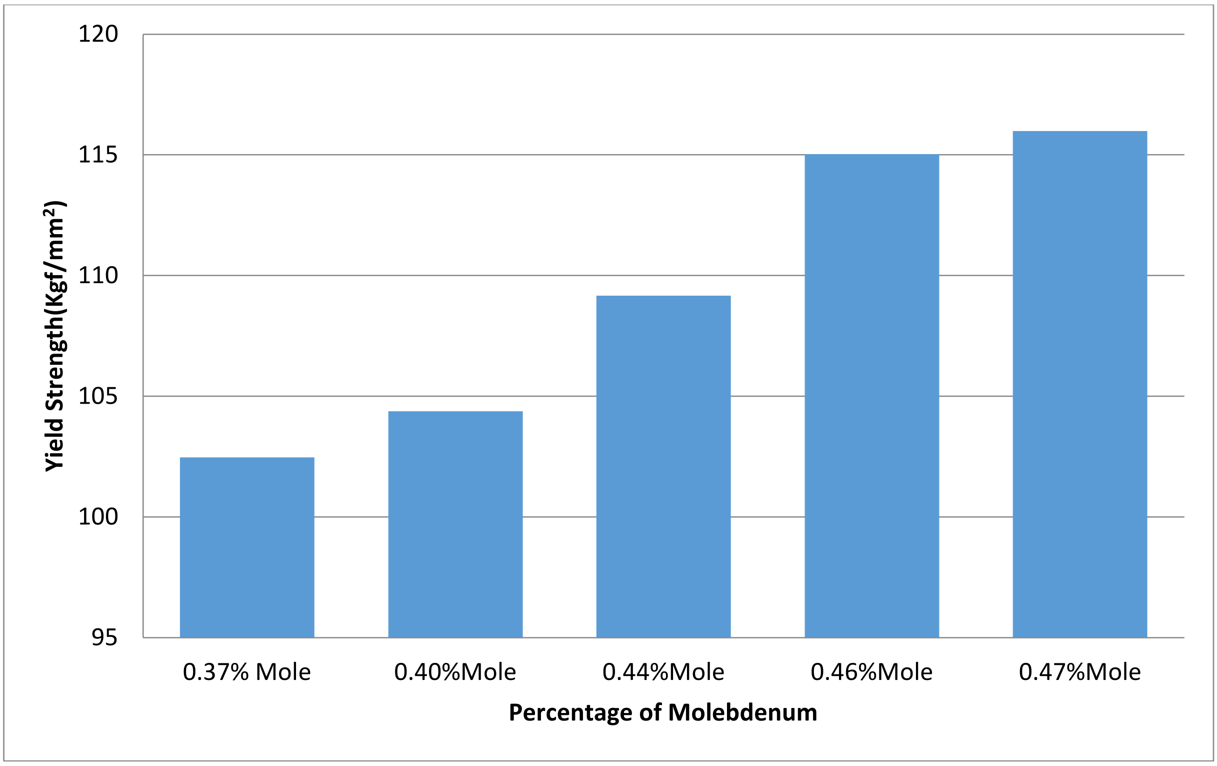

Fig. 18: Molybdenum vs Ultimate Tensile Strength

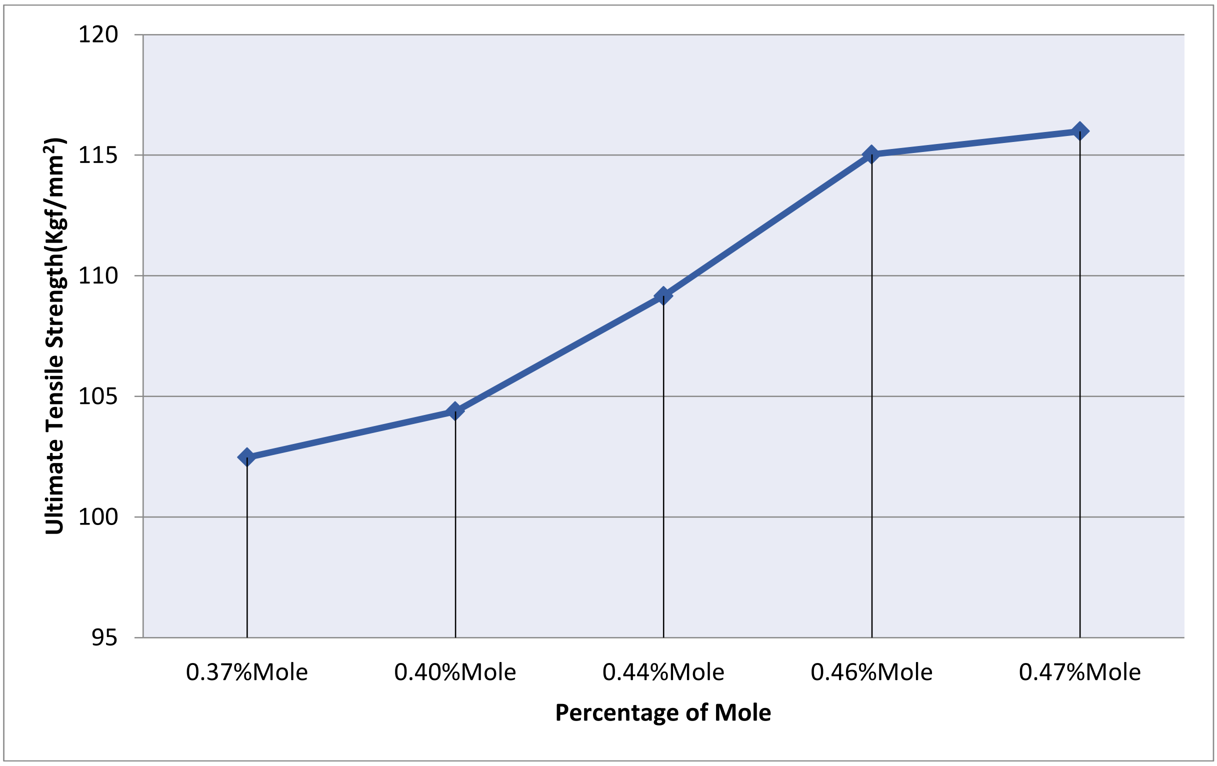

Fig. 19: Molybdenum vs Ultimate Tensile Strength

Effect of chromium In Alloy Steel

Addition of chromium increases: Tensile strength, Hardness and Ultimate Tensile Strength.

Observation: If Base Elements of a steel alloy are such as C –0.29% , Si- 0.30%, Mn-0.67%
S-0.012%, P-0.018%, Ni-1.56%, Mo-0.22% and V-0.12%
With Chemical Composition given above an observation for change in percentage of **Chromium vs Ultimate Tensile Strength** has been taken as shown in table 5.2.

Table 2-Chromium vs Ultimate Tensile Strength

Sample No.	% Of Cr	Ultimate Tensile Strength
1	1.30	813 MPa
2	1.41	815MPa
3	1.53	832 MPa
4	1.63	881 MPa
5	1.67	1001 MPa

Effect of Nickel in Alloy steel

Addition of nickel in alloys, as compared to plane carbon steel, are characterized by

- Higher tensile strength, Higher toughness values, Improved fatigue strength, Improved impact resistance, Improved shear strength

Observation: If Base Elements of a steel alloy are such as C –0.32% , Si- 0.28%, Mg-1.35%, S-0.009%, P-0.024%, Cr-0.62%, Mo-0.41% .

With Chemical Composition given above an observation for change in percentage of Nickel vs Ultimate Tensile Strength has been taken as shown in table 5.3.

Table 3-Nickel vs Ultimate Tensile Strength

Sample No	% Nickel	UTS
1	0.75	100.85 Kgf /mm^2
2	0.807	102.39 Kgf /mm^2
3	0.81	107.15 Kgf /mm^2
4	0.815	109.17 Kgf /mm^2
5	0.84	114.24 Kgf /mm^2

Effect of Carbon in Alloy Steel

In alloy steel carbon contents effects the: Machine ability, Melting point, Tensile strength, Hardness

*Observation:*If Base Elements of a steel alloy are such as Si-0.25%, Mn-0.81%, S-0.007%,

P-0.016%, Ni-0.020%, Cr-0.087%, Mo-0.01%, V- 0.005% With this Chemical Composition an observation for change in percentage of Carbon vs Ultimate Tensile Strength has been taken as shown in table 4.

Table 4-Carbon vs Ultimate Tensile Strength

Sample No.	% Carbon	UTS
1	0.50	955 MPa
2	0.51	957 MPa
3	0.53	965 MPa
4	0.54	970 MPa
5	0.55	977 MPa

Effect of Molybdenum in alloy Steel

By addition of molybdenum, these properties of steel alloy can be significantly improves: Harden ability, Ductility, Toughness, Temperature properties and Tensile Strength

Observation: If Base Elements of a steel alloy are such as C –0.33%, Si- 0.20%, Mg-1.34%, S-0.016%, P-0.030%, Ni-1.08% , Cr-0.75% With this Chemical Composition as given above an observation for change in percentage of **Molybdenum vs Ultimate Tensile Strength** has been taken and shown in table 5.

Table 5 -Molybdenum vs Tensile Strength

Sample No.	% Molybdenum	Ultimate Tensile Strength
1	0.37	102.47 Kgf/mm^2
2	0.40	104.38 Kgf/mm^2
3	0.44	109.16 Kgf/mm^2
4	0.469	115.03 Kgf/mm^2
5	0.47	115.99 Kgf/mm^2

CONCLUSIONS

The Present Study shows the effect of varying percentage of individual alloying elements on mechanical behavior of cast steel. In this study,the effects of individual percentage of alloy element varied keeping the constant percentage of rest of otherelements in composition.

1. In Study of alloy element manganese with chemical composition (C-.26%, Si-0.43%, Mn-1.08%, S-0.006%, P-0.007%) steel is casted. Yield Strength has been found 28.55 TSI. It has been observed that as the percentage of manganese increases, yield strengthincreases.
2. In study of alloy element chromium with chemical composition (C-0.29%, Si-0.30%, Mn-0.675%, S–0.12%, P-0.018%, Ni-1.56 %, Cr-1.30%, Mo-0.22%,V-0.12%) steel is casted. The ultimate tensile strength (UTS) has been found 813 MPa. It has been observed that as the percentage of chromium increases,the ultimate tensile strength (UTS) also increases.
3. In the study of alloy element nickel with chemical composition (C-0.32%,Si -0.289% , Mn-1.356%, S-0.009, P-0.24%, Ni-0.75%, Cr-0.618%, Mo -0.41%) steel is casted. The results shows that theultimate tensile strength (UTS) has been found 100.85 kg force/mm^2 and UTS has been found increased on increase of percentage of nickel content.
4. In study of alloy element carbon with chemical composition (C-0.50%,Si -0.25%, Mn-0.81%, S- 0.007, P-0.016%, Ni-0.020%, Cr-0.087%, Mo-0.010%, V–0.005%) steel is casted. The ultimate tensile strength (UTS) has been found 955MPa and found increased on increase of percentage of carbon content.
5. In study of alloy element molybdenum with chemical composition (C-0.33%,Si -0.20%, Mn-1.34%, S- 0.016, P-0.030%, Ni-1.08%, Cr-0.75%, Mo -0.37%) steel is casted. The ultimate tensile strength (UTS) has been

found 102.47 Kg force /mm^2. When percentage of molybdenum increased, UTS also found increased.

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