CHARACTERIZATION AND ANALYSIS OF STEEL-NICKEL ALLOY CONNECTING ROD BY ANSYS APPROACH

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Abstract: **Connecting rod is a vital link between piston and crank pin. Together with the crank, it forms a simple mechanism that converts reciprocating motion into rotating motion. With the advent technological improvements in metallurgical processes the present research focus shifted to metal alloys. In this thesis, the mechanical properties of Steel and nickel (9.06%) alloy were calculated and subjected to simulation in ANSYS. The addition of nickel, as an alloying element enhances tensile strength, imparts hardness, toughness and reduces rust formation. These properties are essential for a connecting rod and the stress strain analysis was carried out for total deformation, equivalent stress, and equivalent strain and the corresponding results were plotted.**

Keywords: **Connecting rod, Steel-Nickel, Big end and Small end, Tensile Strength, Impact Strength, Yield Strength, CATIA V5, ANSYS.**

1. INTRODUCTION

Steel is the generic term for a large family of Iron-Carbon alloys, which are malleable, within some temperature range, immediately after solidification from the molten state. The principle raw materials used in steel making are iron ore, coal, and limestone. These materials are converted in a blast furnace into a product known as 'pig iron,' which contains considerable amounts of carbon (above 15%), manganese, sulfur, phosphorous, and silicon. Pig iron is hard, brittle, and unsuitable for direct processing into wrought forms. Pig iron was named long ago when molten iron was poured through a trench in the ground to flow into shallow earthen holes. The arrangement looked like new born pigs suckling. The central channel became known as the "sow," and the molds were "pigs."

Steel making is the process of refining pig iron as well as iron and steel scrap by removing undesirable elements from the melt and then adding desirable elements in predetermined amounts. A primary reaction in most steel making is the combination of carbon with oxygen to form a gas. If dissolved oxygen is not removed from the melt prior to or during pouring, the gaseous products continue to evolve during solidification. If, the steel is strongly deoxidized elements, no gas is evolved, and the steel is called "killed" because it lays quality in the molds. Increasing degree of gas evolution (decreased de-oxidation) characterize steels called "semi killed," "capped," or "rimmed." The degree of de-oxidation effects some of the properties of the steel. In addition to oxygen, liquid steel contains measurable amounts of dissolved hydrogen and nitrogen. For some critical steel applications, special de-oxidation practices as well as vacuum treatments may be used to reduce and control dissolved gases.

2. LITERATURE SURVEY

2.1 EFFECTS OF CHIEF ALLOYING ELEMENTS:

Carbon – is generally considered to be the most important alloying element in steel and can be present up to 2% (although most welded steels have less than 0.5%). Increased amounts of carbon increases hardness and tensile strength, as well as response to heat treatment (hardenability). Increased amounts of carbon will reduce weldability.

Sulfur – is usually an undesirable impurity in steel rather an alloying element. In amounts exceeding 0.05% it tends to cause brittleness and reduce weldability. Alloying additions of sulfur in amounts from 0.10% to 0.30% will tend to improve the machinability of steel. Such types may be referred to as "re-sulfurized" or "free-machining". Free-machining alloys are not intended for use where welding is required.

Phosphorus – is generally considered to be an undesirable impurity in steels. It is normally found in amounts up to 0.04% in most carbon steels. In hardened steels, it may tend to cause embrittlement. In low-alloy high –strength steels, phosphorus may be added in amounts up to 0.10% to improve strength and corrosion resistance.

Silicon – Usually only small amounts (0.20%) are present in rolled steel when it is used as a deoxidizer. However, in steel castings, 0.35 to 1.00 % is usually present. Silicon dissolves in iron and tends to strength it. Weld metal usually contains approximately 0.50% silicon as a deoxidizer. Some filler metals may contain up to 1% to provide enhanced cleaning deoxidization for welding on contaminated surfaces. When these filler metals are used for welding on clean surfaces, the resulting weld metal strength will be markedly increased. The resulting decrease in ductility could resent cracking problems.

Manganese – steels usually contain at least 0.30% manganese because it assists in the de-oxidation greater strength by increasing the hardenability of the steel. Amounts of up to 1.5% can be found in some carbon steels.

Chromium – is a powerful alloying element in steel. In strongly increases the hardenability of steel, and markedly improves the corrosion resistance of alloys in oxidizing media. Its presence in some steels could cause excessive hardness and cracking in and adjacent to welds. Stainless steels may contain in excess of 12% chromium.

Molybdenum – this element is a strong carbide former and is usually present in alloy steels in amounts less than 1%. It increases hardenability. It often improves the toughness and ductility of the steel, even with the increased strength and hardness it brings. It is frequently used to improve toughness at low temperature.

Aluminum – is added to steel in very small amounts as a deoxidizer. It also is a grain refiner for improved toughness; steels with moderate aluminum additions have been made to a "fine grain practice".

Vanadium – the addition vanadium results in an increase in the hardenability of steel. It is very effective, so it is added in minute amounts. At greater than 0.05%, there may be a tendency for the steel to become embrittled during thermal stress relief treatments.

2.2 A GLIMPSE OF CONNECTING ROD:

A connecting rod is a rigid member which connects a piston to a crank or crankshaft in a reciprocating engine. Together with the crank, it forms a simple mechanism that converts reciprocating motion into rotating motion.

A connecting rod may also convert rotating motion into reciprocating motion, its original use. Earlier mechanisms, such as the chain, could only impart pulling motion. Being rigid, a connecting rod may transmit either push or pull, allowing the rod to rotate the crank through both halves of a revolution. In a few two-stroke engines the connecting rod is only required to push.

Today, the connecting rod is best known through its use in internal combustion piston engines, such as automobile engines. These are of a distinctly different design from earlier forms of connecting rod used in steam engines and steam locomotives.

2.2.1 SMALL END AND BIG END:

The **small end** attaches to the piston pin, gudgeon pin or wrist pin, which is currently most often press fit into the connecting rod but can swivel in the piston, a "floating wrist pin" design. The **big end** connects to the crankpin (bearing journal) on the crank throw, in most engines running on replaceable bearing shells accessible via the 'connecting rod bolts' which hold the bearing "cap" onto the big end. Typically there is a pinhole bored through the bearing on the big end of the connecting rod so that pressurized lubricating motor oil squirts out onto the thrust side of the cylinder wall to lubricate the travel of the pistons and piston rings. Most small two-stroke engines and some single cylinder four-stroke engines avoid the need for a pumped lubrication system by using a rolling-element bearing instead, however this requires the crankshaft to be pressed apart and then back together in order to replace a connecting rod.

2.2.2 STRESS AND FAILURE :

The connecting rod is under tremendous stress from the reciprocating load represented by the piston, actually stretching and being compressed with every rotation, and the load increases as the square of the engine speed increase. Failure of a connecting rod, usually called **throwing a rod**, is one of the most common causes of catastrophic engine failure in cars, frequently putting the broken rod through the side of the crankcase and thereby rendering the engine irreparable; it can result from fatigue near a physical defect in the rod, lubrication failure in a bearing due to faulty maintenance, or from failure of the rod bolts from a defect, improper tightening or over-revving of the engine. In an unmaintained, dirty environment, a water or chemical emulsifies with the oil that lubricates the bearing and causes the bearing to fail. Re-use of rod bolts is a common practice as long as the bolts meet manufacturer specifications. Despite their frequent occurrence on televised competitive automobile events, such failures are quite rare on production cars during normal daily driving. This is because production auto parts have a much larger factor of safety, and often more systematic quality control.

Aluminum connecting rod for 4-stroke engine, fatigue breakage and subsequent impact with the crankshaft

3. FABRICATION OF STEEL-NICKEL ALLOY

The primary base metal selected for the casting is AISI 1141 carbon steel. This steel is a medium carbon steel and possesses all the required characteristics which are essential, if used as a material alloy for the connecting rod. Carbon steels contain carbon as the primary alloying element. Small quantities of molybdenum, chromium, nickel, aluminum, and copper are also present in these steels. They contain 0.4% silicon and 1.2% manganese. They are designated by AISI four-digit numbers.

3.1 PRACTICAL WORKING:

The working spot has been captured and given below. Both the metals were melted at temperatures ranging from 1560° C to 1640° C, in the Induction furnace.

Molten metal in the crucible

The molten metal has been poured into a square shaped mould and then allowed to solidify to the open air. Later, when the metal is solidified, it has been drawn out. The metal obtained metal has given in the below picture. This metal, which is the alloy of Steel-Nickel, now has been tested mechanically and found the desired properties which are essential for the analysis by ANSYS approach.

Steel-Nickel metal alloy after solidification

The obtained specimen has a weight of approximately 12.2 kilograms. And the corresponding dimensions of the specimen are 160 mm length, 160 mm breadth and 60 mm thickness. The standards of the specimen were calculated appropriately before the metal alloy subjected to the mechanical characterization.

Though the metal has been selected and worked preciously; it is impossible to avoid the practical impossibilities and as a result few unavoidable alloying elements has been a part of the alloy and were present in a minute and negligible amounts. As a result of this, the characterization of the practical alloy has been subjected to few alterations compared to the theoretical characterization.

4. EXPERIMENTAL ANALYSIS

4.1 CHEMICAL CHARACTERIZATION OF THE STEEL-NICKEL ALLOY :

Equipment used: Optical emission Spectrometer BAIRD DV6

S.No.	CONTENT	PERCENTAGE %
1.	HEAT NO.	451
2.	CARBON ©	0.48%
3.	NICKEL (Ni)	9.06%
4.	MANGANESE (Mn)	0.22%
5.	PHOSPHORUS(P)	0.16%
6.	IRON (Fe)	Remainder

Chemical characterization of the Steel-Nickel Alloy

Hence as expected the Nickel content ranges around 9% in the steel; this imparts high impact strength and good hardenability to the steel. The addition few alloying elements like Phosphorus might impact few characteristics of the Steel but they can't be avoided due to the few practical imperfections and difficulties.

4.2 TENSILE CHARACTERISTICS OF THE STEEL-NICKEL ALLOY:

The casted metal after solidification has been subjected to various cutting and machining operations. For the tensile test, the metal has been cut into to the shape of a Dog bone, which is given below.

Tensile test specimen

Input data:

Specimen shape : Solid Round

Material type : Steel

Specimen Description : 160*160*60 mm steel-nickel alloy

Specimen Diameter : 12.49 mm

Initial gauge length : 50 mm

Pre load value : 0 KN

Max. Load : 600 KN

Max. Elongation : 280 mm

Specimen cross section Area : 122.52mm^2

Final specimen Diameter : 7.93 mm

Final Gauge Length : 69.38 mm

Final Area : 49.39 mm

The tensile test was carried out in an UTM (Universal Testing Machine). UTM is given in below figure:

Universal testing machine

The metal after subjected to tensile loading is given in the below figure

Tensile test specimen after breakage

Tensile properties:

S.No.	PROPERTY	VALUE
1.	Tensile Strength (Mpa)	725.20
2.	Yield Strength (Mpa)	596.2
3.	Elongation (%)	21.6

Tensile properties of the Steel-Nickel Alloy

Hence as expected the tensile characteristics of the specimen were increased to some extent and stood at approximately 725 Mpa or 725 N/mm^2. The corresponding yield strength for the material is given as 593 N/mm^2 and the metal alloy possesses elongation, which is given by 21.6%.

Nevertheless these characteristics were compared to standard AISI 1141 carbon steel for the better analysis and understanding of the properties obtained through testing.

4.3 IMPACT CHARACTERISTICS OF STEEL-NICKEL ALLOY:

The casted metal after solidification has been subjected to various cutting and machining operations. For the Charpy impact test, the metal has been cut into to the shape of rectangular billet. The test specimen is given in the below figure.

Charpy impact test specimen

Sample Reference : 160*1601*60 mm

Nature of the Test : CHARPY IMPACT TEST

Type of Notch : “V”

Notch Depth : 2 mm

Specimen Dimensions: 10*10*55 mm

The impact test was carried out in an Impact Testing Machine. Impact testing machine is given in below figure:

Impact test equipment

The test specimen has been subjected to impact test and the respective specimen is given in the below figure:

Impact test specimen after breakage

Impact strength of the specimen

S.No.	S.ID	Impact Energy – Joules
1.	160*160*60 mm	35 J

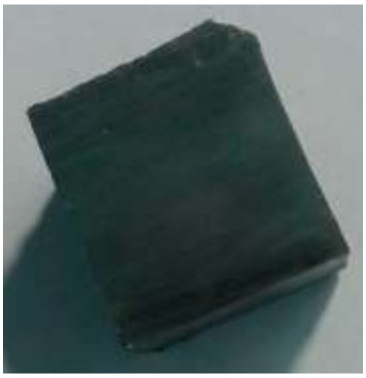
Impact properties of the Steel-Nickel Alloy

	AISI 1141 CARBON STEEL		STEEL-NICKEL ALLOY	
S.No.	CONTENT	PERCENTAGE %	CONTENT	PERCENTAGE %
1.	HEAT NO.	451	HEAT NO.	451
2.	CARBON C	0.370% - 0.45%	CARBON C	0.48%
3.	SULFUR S	0.080% - 0.13%	NICKEL Ni	9.06%
4.	MANGANESE Mn	1.35-1.65%	MANGANESE Mn	0.22%
5.	PHOSPHORUS P	0.040%	PHOSPHORUS P	0.16%
6.	IRON Fe	97.73-98.2%	IRON Fe	Remainder

The impact strength of the specimen is 35J and by far this is a great feat in the project. Impact strength has been principle feature required in the connecting rods. So if this material has been applied to the connecting rod, then the con rod might have better operating characteristics and that could even resist high fatigue loads and operating temperature and pressures.

4.4 HARDNESS CHARACTERISTICS OF STEEL-NICKEL ALLOY:

The casted metal after solidification has been subjected to various cutting and machining operations. For the hardness test, the metal has been cut into to square shape. The test specimen is given in the below figure.



Brinell hardness test specimen

Sample Reference : 160*1601*60 mm

Nature of the Test : Brinell Hardness Test

Specimen Dimensions : 30*28*26 mm

Brinell Hardness Number

S.No	HB
1.	**173**

Hardness characteristics of the Steel-Nickel Alloy

The Brinell hardness number for the casted alloy has reduced to a bit. It might be due to the inclusion of few impurities like sulfur and phosphorus. Though the reduced value is minute, yet it should be taken care off while working in the industry and while applying this material to any kind of practical working purposes such as manufacturing of bearings for the engines or fabrication of connecting rods.

5. COMPARISON OF STEEL-NICKEL ALLOY WITH A STANDARD AISI 1141 CARBON STEEL

5.1 CHEMICAL CHARACTERIZATION OF THE AISI 1141 CARBON STEEL AND STEEL-NICKEL ALLOY :

Equipment used: Optical emission spectroscope BAIRD DV6

Carbon steels contain carbon as the primary alloying element. Small quantities of molybdenum, chromium, nickel, aluminum, and copper are also present in these steels. They contain 0.4% silicon and 1.2% manganese. They are designated by AISI four-digit numbers.

Upon comparison of Steel-Nickel Alloy Chemical composition with a standard AISI 1141 Carbon steel composition; it is found that small alloying elements were present in both the metals. But the additions of Nickel in the casted alloy enhanced Impact strength of the Steel, which is indeed a desirable and indispensable feature for the connecting rod material, if used.

5.2 TENSILE CHARACTERISTICS OF STANDARD AISI 1141 CARBON STEEL AND STEEL-NICKEL ALLOY:

Tensile properties:

	PROPERTY	AISI 1141 STEEL		STEEL& NICKEL
S. No .	PROPERTY	METRIC	IMPERIAL	VALUE
1.	Tensile Strength (Mpa)	675.00	97900 PSI	725.20
2.	Yield Strength (Mpa)	360.00	52200 PSI	596.2
3.	Elongation (%)	22	22	21.6

Tensile characteristics of Standard AISI 1141 Carbon Steel and Steel-Nickel alloy

As listed clearly, it has been observed that the Tensile strength of the Casted Steel-Nickel Alloy is 725 Mpa, which was considerably greater than the Standard AISI 1141 Carbon Steel which is 675 Mpa. The higher Tensile strength is due to the additions of nickel as an alloying element. This higher strength is an added advantage for the connecting rod material, if used.

5.3 IMPACT CHARACTERISTICS OF STANDARD AISI 1141 CARBON STEEL AND STEEL-NICKEL ALLOY:

S.No.	S.ID	Impact Energy – Joules
1.	160*160*60 mm	11 J
S.No.	S.ID	Impact Energy – Joules
1.	160*160*60 mm	35 J

Impact strength characteristics of Standard AISI 1141 Carbon steel and Steel-Nickel alloy

So, as expected the impact strength of the Casted alloy is considerably increased and stood at 35 J, which is indeed a great result for the application as a connecting rod material. The impact strength for the Standard AISI 1141 Carbon steel was 11 J and for the Casted Steel-Nickel alloy it was 35 J.

The connecting rod is supposed to work under tremendous pressures and temperatures; high impact strength imparts higher with-standing capacities without breaking. Hence, this is the primary reason behind the Casting of Steel-Nickel alloy.

6. ANSYS ANALYSIS

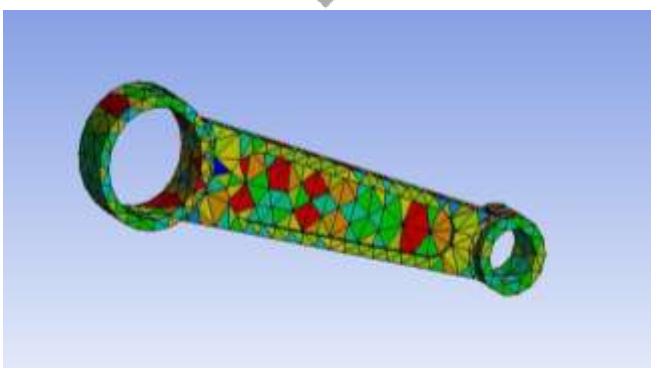
For serving this analysis, the characteristics of the Steel-Nickel alloy has been given to the ANSYS software. And the design of the connecting rod was drawn in CATIA V5 software and saved in the IGS format. Now this file format, containing the drafted connecting rod has to be imported to the geometry of the ANSYS.

After giving all engineering data to the ANSYS software, ANSYS automatically does its work and frames the result. The parameters analyzed in the ANSYS are given below:

- ✓ Total deformation
- ✓ Equivalent stress
- ✓ Equivalent strain

The type of analysis performed is Static Structural analysis. Static structural analysis focuses on the deformation of the object. For this we need to arrange a fixed support to the system by the assumption and then we have to give the load in the other direction; so that the object is subjected to loads as per the given load conditions and the system interprets the result once the solution has been done.

Before solving the above problems ANSYS demands the object and the whole surface to be meshed. Meshing is the process of dividing the object into number of triangular components. This meshing aids the accurate and appropriate distribution of the load throughout the component. Furthermore, meshing enhances the quality of the output result which we get once the solution is done. A sample of the connecting rod, when meshing is applied is given in the below figure. The type of mesh given to the object is a skewness mesh as shown in the below figure.



Skewness mesh of the connecting rod

6.1 TOTAL DEFORMATION:

There are two types of deformations in the ANSYS. Deformation results generally can be in ANSYS Work Bench as total deformation or directional deformation. Both of them are used to obtain displacements from stresses. The main difference is the directional deformation calculates for the deformations in X, Y, and Z planes for a given system. In total deformation, it gives a square root of the summation of the square of x-direction, y-direction and z-direction.

The corresponding load given to the connecting rod for the results of total deformation is 7000 N. This may be an exaggeration, if I explain that this load is nothing in front of the material which we made. To be clearer, the connecting rod absolutely sustained this 7000 N load without any considerable deformations. Hence, once again proved that the Steel-Nickel alloy absolutely sustains the impact loads and deformations in working conditions, if used in the Automobile components.

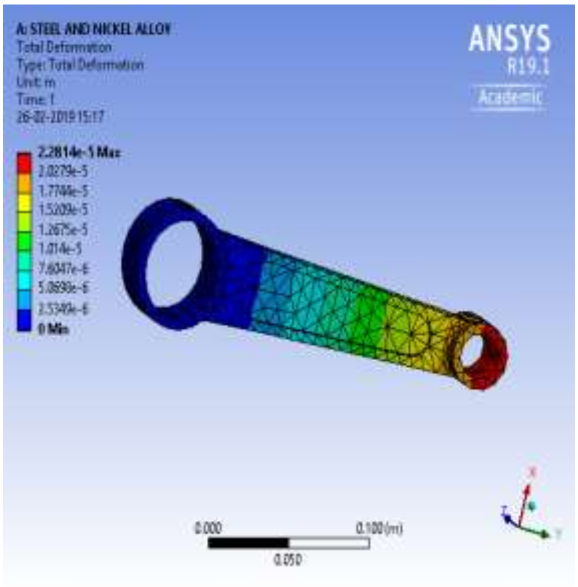
The corresponding result and the drafting model of the connecting rod are presented in the below table and figures respectively.

Object Name	*Equivalent Stress*	*Equivalent Elastic Strain*	*Total Deformation*
State	Solved		
Scope			
Scoping Method	Geometry Selection		
Geometry	All Bodies		
Definition			
Type	Equivalent (von-Mises) Stress	Equivalent Elastic Strain	Total Deformation
By	Time		
Display Time	Last		
Calculate Time History	Yes		
Identifier			
Suppressed	No		
Integration Point Results			
Display Option	Averaged		
Average Across Bodies	No		
Results			
Minimum	166.32 Pa	1.0991e-009 m/m	0. m
Maximum	3.4038e+007 Pa	1.7089e-004 m/m	2.2814e-005 m
Average	1.4115e+007 Pa	7.3044e-005 m/m	7.6068e-006 m
Minimum Occurs On	connecting rod-Free Parts		
Maximum Occurs On	connecting rod-Free Parts		
Information			
Time	1. s		
Load Step	1		
Substep	1		
Iteration Number	1		

Solution for static structural analysis of the connecting rod

The tabular data, which we got after the solution has been done in the ANSYS, clearly demystifies that maximum deformation that occurred for a load of 7000N is 166.32 Pa and the corresponding minimum deformation occurred is 3.4038e+007 Pa.

The drafting image for the same is given in the below figure. The figure shows the Total deformation of the object under loading conditions. There are different color coding's for the amount of load with respect to the time, which shows that what amount of load has been applied at that particular zone and at a particular time period.

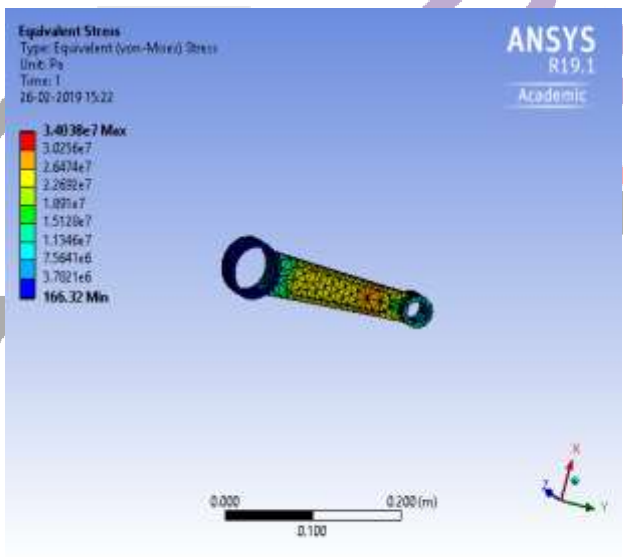


Total deformation of the connecting rod

6.2 EQUIVALENT STRESS DISTRIBUTION:

Equivalent stress (also called *von Mises stress*) is often used in design work because it allows any arbitrary three-dimensional stress state to be represented as a single positive stress value. Equivalent stress is part of the maximum equivalent stress failure theory used to predict yielding in a ductile material.

The corresponding figure for the equivalent stress is given in the below figure.



Equivalent stress distribution in the connecting rod

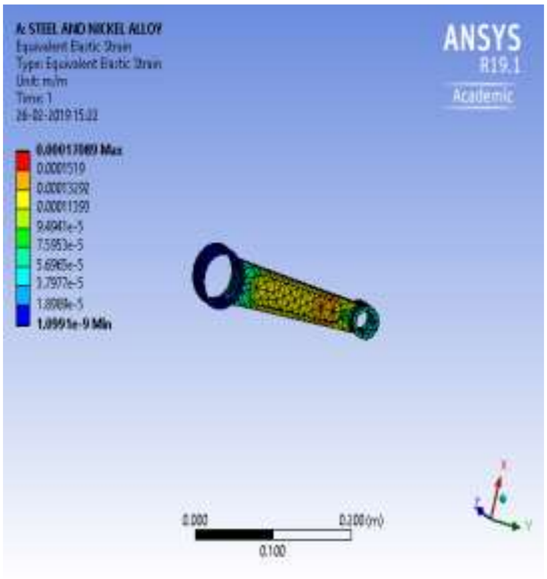
Unlike total deformation, the stress induced in the connecting rod was a bit recognizable as depicted in the above figure. However, it is not a considerable issue, if the material (Steel-Nickel alloy) used for the connecting rod.

6.3 EQUIVALENT STRAIN DISTRIBUTION:

The von Mises equivalent strain increment is derived for the case of large strain simple shear (torsion testing). This is used, in conjunction with the von Mises yield surface, to define the von Mises equivalent stress as well as the incremental work per unit volume. Integration of the equivalent strain increment leads to the definition of the von Mises equivalent strain for torsion.

The equivalent plastic strain gives a measure of the amount of permanent strain in an engineering body. The equivalent plastic strain is calculated from the component plastic strain as defined in the Equivalent stress/strain section.

The respective strain image for the same is given in the below figure.



Equivalent strain in the connecting rod

As illustrated above, the strain distribution in the connecting rod is just recognizable to the human eye. There is nothing like which might affect the performance of the connecting rod or any automobile component with this kind of strain in the object for this particular material. There is strain distribution in the connecting rod, for the given load (7000N) but it is not necessary to take this into account for the effective operation of the connecting rod.

7. CONCLUSION

Connecting rod is a vital link between piston and crank pin. As per the concept of the thesis, the addition of Nickel to the steel considerably increased the characteristics of the alloy. To be more specific, the tensile strength yield strength of the alloy was raised significantly, as well as the elongation decreased to a small amount due to the higher strength. The impact characteristics of the alloy was also soared to substantially higher value when compared to the standard AISI 1141 medium carbon steel. Conversely, the hardness number of the alloy was declined by a negligible amount due to the practical inaccuracies. Nonetheless the casted alloy was subjected to simulation in ANSYS and found out the total deformation, equivalent stress and strain of the connecting rod. As depicted above the Steel-Nickel alloy connecting rod was flawless and resisted not only the deformation under the loading but also the equivalent stress and strain. In a nutshell, the addition of nickel as a main alloying element worked out exceptionally well and the thesis can further be expanded in the future by making few alterations in the composition of the alloy for the fabrication of various automobile components.

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