SIMULATION AND FINITE ELEMENT ANALYSIS OF COMPRESSION HEAD OF A HOMOGENIZER TO ANALYZE THE MECHANICAL STRENGTH WITH CHANGE IN MATERIAL COMPOSITION

Akash Agarwal, Department of Mechanical Engineering, SRMS CET, Bareilly

Amir Hussain Idrisi, Assistant Professor, Department of Mechanical Engineering, SRMS CET, Bareilly

Abstract: *The Homogenizing process has the specific function of reducing the treated product particles to microns in order to improve the mixing process and the stability of the product. This process is used in all those sectors where a perfect emulsion and a high degree of suspension and dispersion are required, with perfectly stable and uniform micronized particles. Compression Head bears the external forces generated due to the moving Pistons, High rate of flow of beverage through the inlet header and the compression forces generated by the Homogenizing Device. In order to accommodate all the forces acting over it, different grades of Stainless steel with different composition of its alloys were studied and successfully verified through the Finite element Analysis.*

Keywords: *Finite Element Analysis, Homogenizer, Compression Head, Composite material, modeling*

1. INTRODUCTION

1.1.1 The Homogenizer

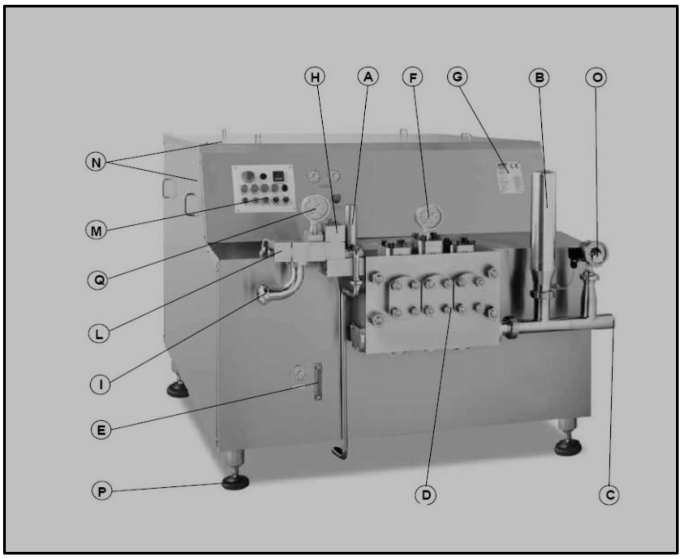
A high-pressure homogenizer is a pump with a homogenisation device. A homogenizer is generally needed when high-efficiency homogenisation is required. The product enters the pump block and is pressurized by the piston pump. The pressure that is achieved is determined by the back-pressure given by the distance between the forcer and seat in the homogenization device. This pressure P1 (Figure 1.1) is always designated as the homogenization pressure. P2 is the back-pressure to the first stage.

1.1.2 The High-pressure pump

In Figure 1.1, the piston pump is driven by a powerful electric motor (1), via belts (2) and pulleys through a gearbox (3) to the crankshaft (10) and connecting-rod transmission, which converts the rotary motion of the motor to the reciprocating motion of the pump pistons (9).

A piston pump is a positive pump and its capacity can only be adjusted by changing the speed of the motor or changing the size of the pulleys. To handle higher pressures, pistons with smaller diameter are installed. This will reduce the maximum capacity, as each machine size has a maximum crankshaft speed. A larger machine has a longer stroke length and/or more pistons. In many cases these pistons also have a larger diameter.

A high-pressure pump has normally three to five pistons (9), running in cylinders in a high-pressure block (8). They are made of highly resistant materials. The machine is fitted with double piston-seals. Water is supplied to the space between the seals to lubricate the pistons. A mixture of hot condensate and steam can also be supplied to prevent reinfection when the homogenizer is placed downstream in aseptic processes. A piston pump will always generate a pulsating flow. The acceleration and deceleration of the liquid will create a pulsating pressure in the suction pipe. To avoid cavitation in the pump, there is always a damper on the suction pipe to reduce the pulsation. On the outlet side, the pulsation might create vibrations and noise, so the outlet pipe is also equipped with a damper. As it is a positive pump, a piston pump should not operate in a series of other positive pumps, unless there is a bypass – otherwise the result can be extreme pressure variations and damaged equipment. If the flow can be stopped downstream of a high-pressure pump, a safety device must be installed that opens before the pipe bursts.



A - Safety valve with drain pipe -
B - Product inlet lung -
C - Product inlet -
D - Compression head -
E - Oil level control -
F - Pressure indicator -
G - Identification label -
H - Homogenizing chamber 1 stage -
I - Product outlet -
L - Homogenizing chamber 2 stage -
M - Control panel -
N - Casing -
O - Inlet product pressure gauge with allarm switch -
P - Adjustable foot -
Q - 2nd stage pressure gauge -

Figure 1.1 Homogenizing Machine

1.1.3 The Homogenisation device

Figure 1.2 shows the homogenisation and hydraulic system. The piston pump boosts the pressure of the milk from about 300 kPa (3 bar) at the inlet to a homogenisation pressure of 10 – 25 MPa (100 – 250 bar), depending on the product. The pressure to the first stage before the device (the homogenisation pressure) is automatically kept constant. The oil pressure on the hydraulic piston and the homogenisation pressure on the forcer balance each other. The hydraulic unit can supply both first and second stage with an individually set pressure. The homogenisation pressure is set by adjusting the oil pressure. Actual homogenisation pressure can be read on a pressure gauge.

Homogenisation always takes place in the first stage. The second stage basically serves two purposes:

- Supplying a constant and controlled back-pressure to the first stage, giving best possible conditions for homogenisation
- Breaking up clusters formed directly after homogenisation as shown in Figure 1.2.

The parts in the homogenisation device are precision-ground. Its seat is at an angle that makes the product accelerate in a controlled way, thereby reducing the rapid wear and tear that would otherwise occur.

Milk is supplied at high pressure to the space between the seat and forcer. The distance between the seat and the forcer is approximately 0.1 mm or 100 times the size of the fat globules in homogenized milk. The velocity of the liquid is normally 100 – 400 m/s in the narrow annular gap.

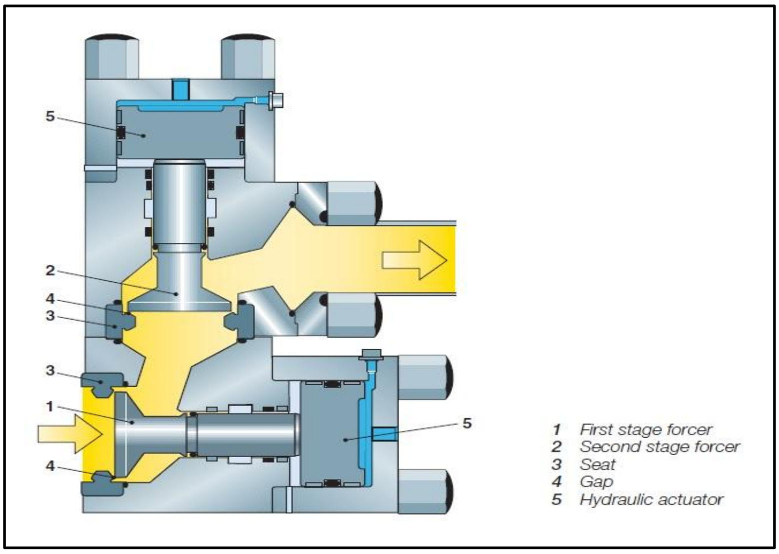


Figure 1.2 Components of two stage homogenisation device

The higher the homogenisation pressure, the higher the speed. Homogenisation takes 10 – 15 microseconds. During this time, all the pressure energy delivered by the piston pump is converted into kinetic energy. Part of this energy is converted back to pressure again after the device. The other part is released as heat; every 40 bar in pressure drop over the device gives a temperature rise of 1 °C. Less than 1 % of the energy is utilized for homogenisation, but nevertheless, high-pressure homogenisation is the most efficient method available.

1.2 Homogenization

This process reduces the size of fat globules of milk or pulp by pumping it at a high pressure through a small orifice, called valve. The device for size reduction is called a homogenizer which subjects fat particles to a combination of turbulence and cavitation. Homogenization is carried out at temperatures higher than 37°C (99°F). The process causes splitting of original fat globules (average diameter approximately 3.5 µm) into a very large number of much smaller fat globules (average size <1 µm). As a consequence, a significant increase in surface area is generated. The surface of the newly generated fat globules is then covered by new membrane formed from milk proteins. Thus, the presence of a minimum value of 0.2 g of casein/g fat is desirable to form to coat the newly generated surface area. As milk is pumped under high-pressure conditions, the pressure drops causing breakup of fat particles. If the pressure drop is engineered over a single valve, the homogenizer is deemed to be single-stage homogenizer. It works well with low-fat products or in products where high viscosity is desired as in creams and sour cream manufacture.

On the other hand, homogenizers reducing fat globule size in two stages are called dual-stage homogenizers. In the first stage, the product is subjected to high pressure, for example, 13.8MPa (2,000psi) which results in breakdown of the particle size diameter to an average of less than 1 µm. Then the product goes through the second stage of 3.5 MPa (500 psi) to break the clusters of globules formed in the first stage. The dual-stage homogenization is appropriate for fluids with high-fat and solids-not-fat content or whenever low viscosity is needed.

Homogenized milk does not form a cream layer (creaming) on storage. It displays whiter color, fuller body, and flavor characteristics. Homogenization leads to better viscosity and stability in cultured products by fully dispersing stabilizers and other ingredients in ice cream, yogurt, and other formulated dairy products.

AISI 304 and 316 stainless steel has properties like better corrosion resistance, high ductility, excellent drawing, forming and spinning properties, so it is used in application like chemical equipment, flatware utensils, coal hopper, kitchen sinks, marine equipment etc.

But despite having excellent properties of these materials, SS 329 grades of material provide all the above properties along with the improved Tensile strength and compression strength which leads to greater sustenance to fracture.

2. PROBLEM FORMULATION

Below picture is of Compression Head of the Homogenizer onto which Hair line crack has been developed on its surface and had undergone through the Heavy leakage of the Product (Mango Pulp). This had occurred because of the Heavy Usual and Unusual forces acting on it in a sinusoidal manner which is made of the material either of SS 304L or SS 316L.

Figure 2.1: Leakage occurred from Compression head because of Hair line crack on its surface with SS 316L grade of material

The objective of the work is to select a material which must be compatible with the desired properties, necessary for food processing equipment and have high strength which cold able to sustain high pressure of fluids and dynamic stresses developed during the process.

3. MATERIAL INVESTIGATION

In order to accommodate the forces acting on the Compression Head of Homogenizer, certain grades of Stainless steel with different composition of its alloys are tested on simulation software's and its impact viz. Mechanical strength are studied through the Finite element Analysis.

3.1 Comparison of SS 304 and SS 316 Vs SS 304L and SS 316L

Stainless steel type 316 and type 304 are raw material grades for stainless steel.

The common ASTM specifications that cover stainless steel bolts are A193, A320 and F593.

a) Type 316 stainless has a unique chemical composition which includes 16% chromium, 10% nickel and 2% molybdenum.

b) Type 304 stainless has 18% chromium, 8% nickel and no molybdenum (this is where the "18-8" designation comes from).

c) The Chemical Properties, Physical properties and Mechanical Properties have been given by the POSCO Company of Europe. These are as follows:-

Table 3.1 Comparison of Physical, Chemical and Mechanical properties of different SS material grades

Chemical Composition of Stainless Steel Alloys					
%	SS 304	SS 304 L	SS 316	SS 316 L	SS 329 LD
C	0.08	0.03	0.08	0.03	< 0.03
Mn	2	2	2	2	2.3-2.7
Si	0.75	0.75	0.75	0.75	0.3-0.6
P	0.045	0.045	0.045	0.045	NA
S	0.03	0.03	0.03	0.03	NA
Cr	20	20	18	18	19.0-22.0
Ni	8	10.5	10	10	2.0-4.0
Mo	0	0	2	2	1.3-2.0
N	0.1	0.1	0.1	0.1	0.14-0.2
Mechanical Properties of Stainless Steel alloys					
Grade	SS 304	SS 304 L	SS 316	SS 316 L	SS 329 LD
Tensile Strength (MPa) minimum	515	485	515	485	789
Ultimate Tensile Strength (MPa)	586	621	579	558	574
Compression Strength (MPa)	210	210	212	212	220
Proof Yield Strength 0.2% (MPa)	205	170	205	170	> 450
Elongation (%) min	40	40	40	40	34
Hardness Brinell HB (max)	201	210	217	217	250-310
Physical Properties of Stainless Steel alloys					
Density (Kg/m3)	8000	8000	8027	8027	7710
Elastic Modulus (GPa)	193	193	200	200	210
Mean Expansion of Thermal Coefficient (µm/m/°C)	17.2	17.2	16.5	16.5	13.2
Thermal Conductivity (W/mK)	16.2	16.2	14.6	14.6	16.5
Specific Heat 0-100°C (J/KgK)	500	500	485	485	520
Electrical Resistivity (nΏm)	720	720	740	740	750

4. MODELING AND ANALYSIS

4.1 FEM ANALYSIS

For carrying out the analysis, following Simulation Software were used to investigate the material strength, corrosion resistive, longer life span and improved hardness percentage to sustain usual and unusual forces on the compression head of the Homogenizer. Software used are as follows:

a) CREO PARAMETRIC

It had been used for generating the simulation drawing of the machine component as per the specifications and dimensions given by the OEM.

b) ANSYS

This software was used to:

- Analyze the material strength at a particular load criteria.
- Generating the curves to distinguish the properties of different grades of SS material.
- Calculating the life span of the component.
- The sustenance and resistance to corrosive environment.

It had been assumed that the Product - Pulp mixture pressure inside the compression block raised from 0 to 100 bar. Such a tremendously high pressure generated inside the block create heavy stresses on its surfaces and lead to the permanent deformation and hair line crack which progressed to give heavy leakages from the system.

4.2 Steps carried out for FEM process

Step 1: Firstly simulation drawing had been prepared for Compression Head of Homogeniser on CREO Parametric 2.0 via considering all the dimensions as given by the OEM.

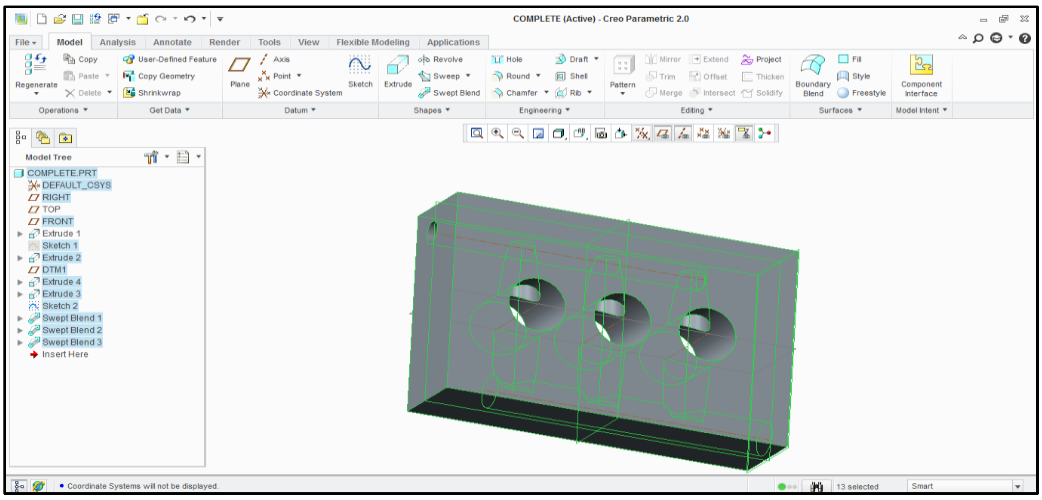


Figure 4.1 Modeling of Compression Block

ISSN: 2278-6252
Impact Factor: 6.655

Step 2: After preparing the simulation drawing via PROE, it had been analyzed through ANSYS software. Compression block.igs had been opened in the ANSYS 16.0 software and various physical and mechanical properties had been imported separately for SS 304 L compression block, SS 316 L compression block and SS 329 LD compression block. Then meshing is done using Hex Dominant cuboidal nodal element shown in figure

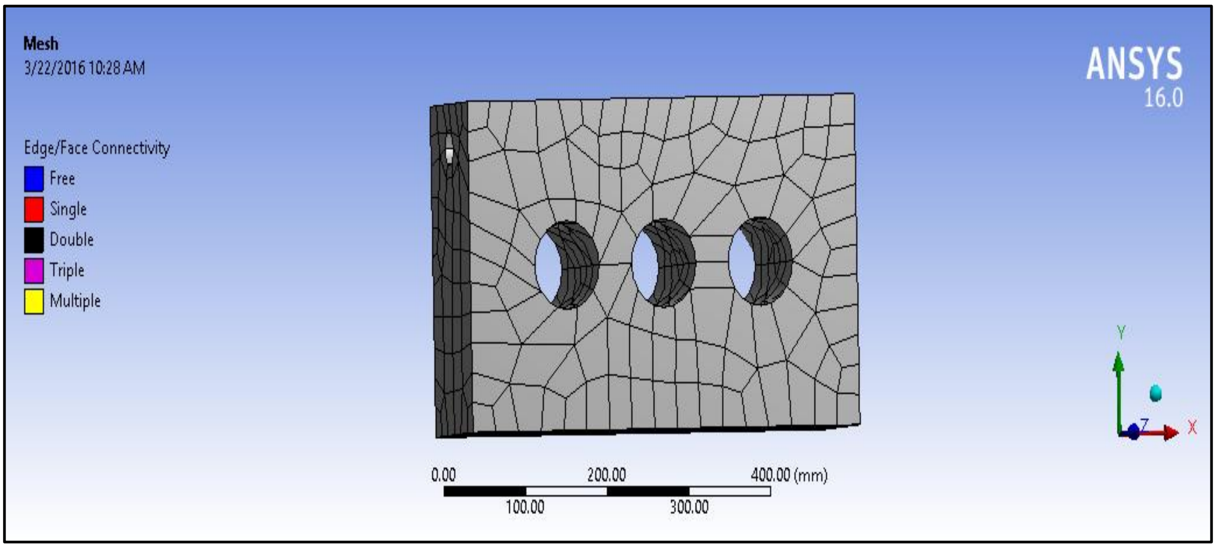


Figure 4.2 Meshed Compression Block

Step 3: After the generation of mesh, Boundary conditions was incorporated on compression block, by keeping all the ends fixed other than the front end and then pressure had been applied on the maximum stress prone area as shown in figure.

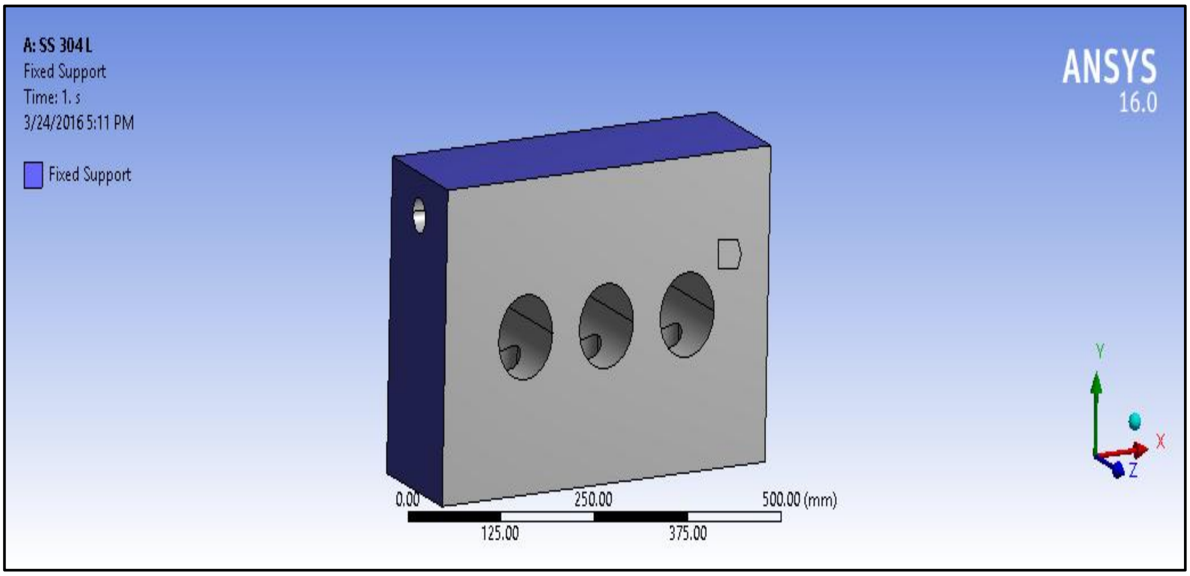


Figure 4.3 Fixed support on Compression Block

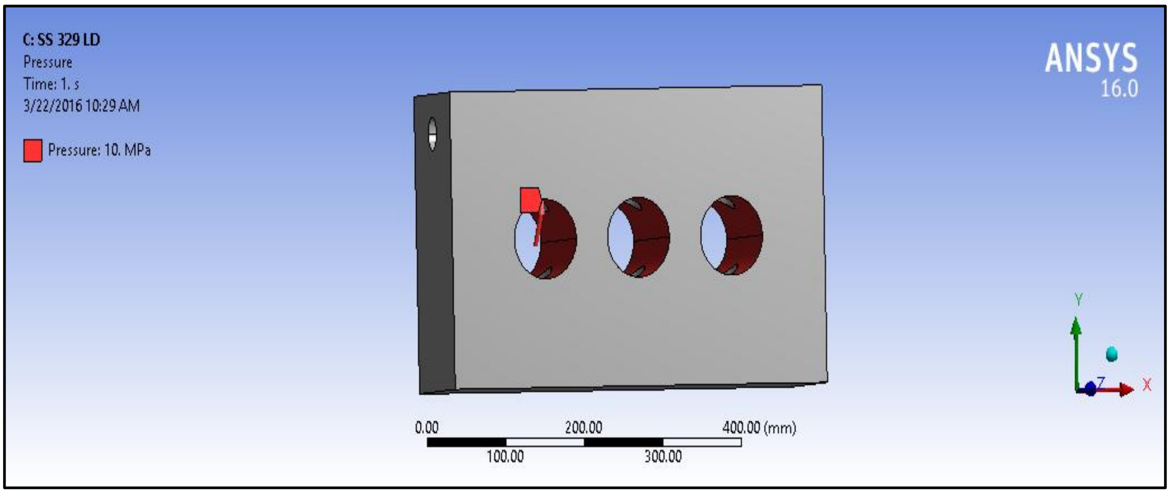


Figure 4.4 Pressure applied on Compression Block

Step 4: For carrying out the analysis for different materials, various parameters were selected and then solution was done by clicking on "solve" option. By this step our problem got analyzed and solved with ANSYS, also the results were plotted by general post processor. After this step we can easily read any of the result as per our requirement like Equivalent stress, Equivalent elastic strain, Max Shear elastic strain, total deformation etc.

For optimization we took pressure at high stress zone area on front end as 10 MPa and noted the Equivalent stress, Equivalent elastic strain, Max Shear elastic strain, total deformation.

The results obtained through analysis for all the compression block i.e. of SS 304 L, SS 316 L and SS 329 LD are as follows:

❖ <u>**Equivalent Von-Mises Stress**</u>

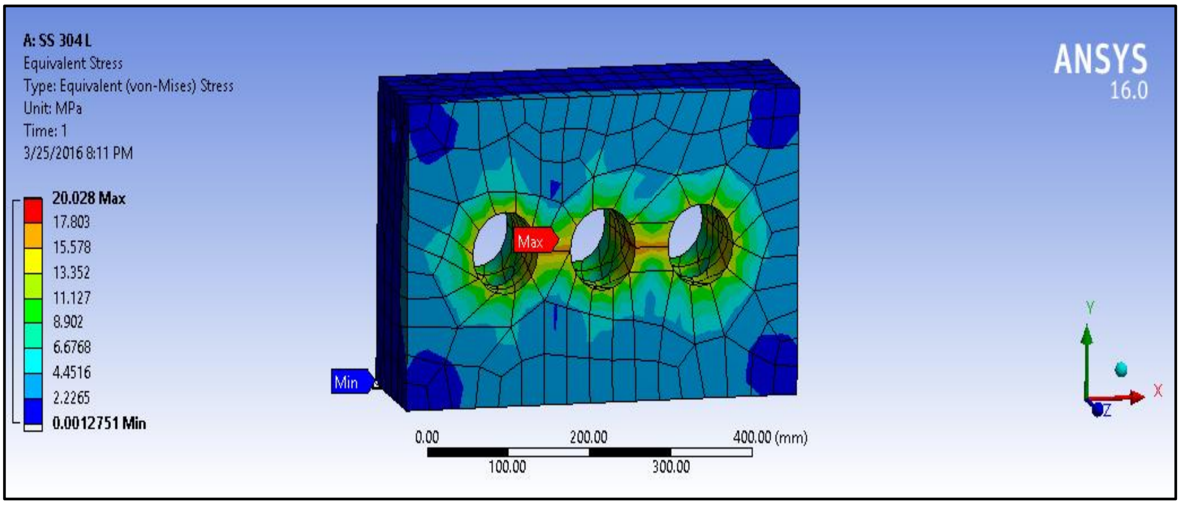


Fig 4.5: Equivalent Von-Mises Stress for SS 304L

ISSN: 2278-6252
Impact Factor: 6.655

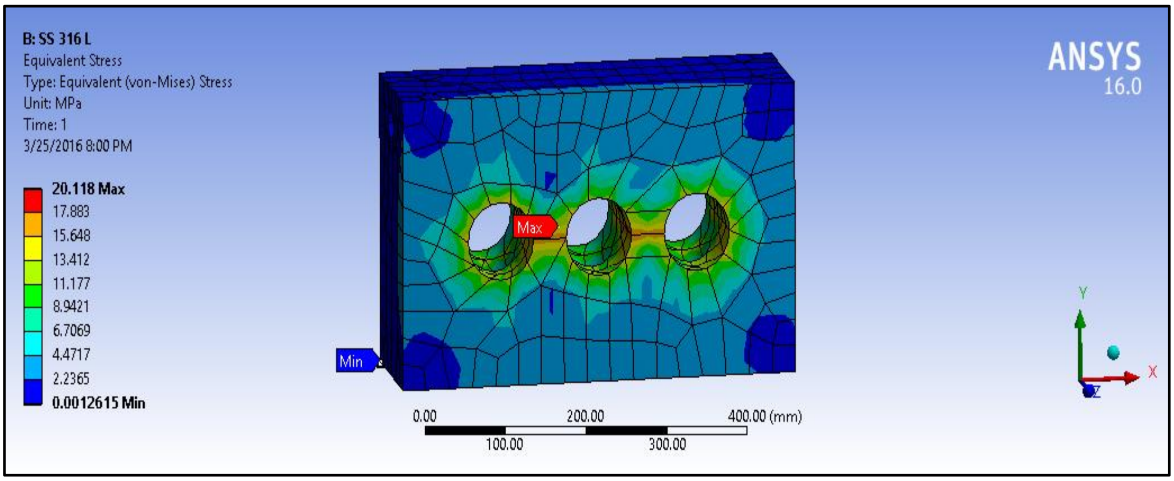


Fig 4.6: Equivalent Von-Mises Stress for SS 316L

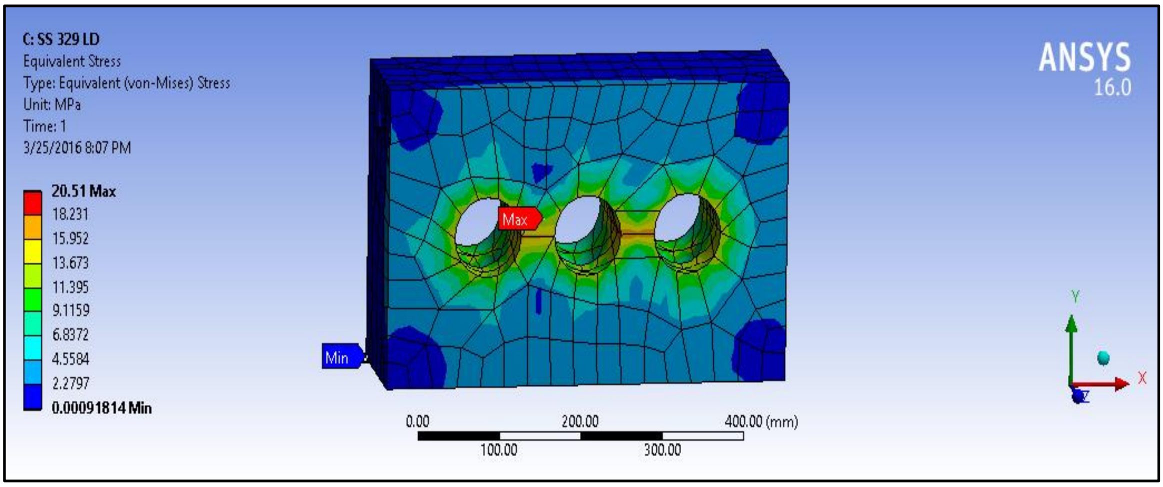


Fig 4.7: Equivalent Von-Mises Stress for SS 329LD

- **Maximum Principal Elastic Strain**

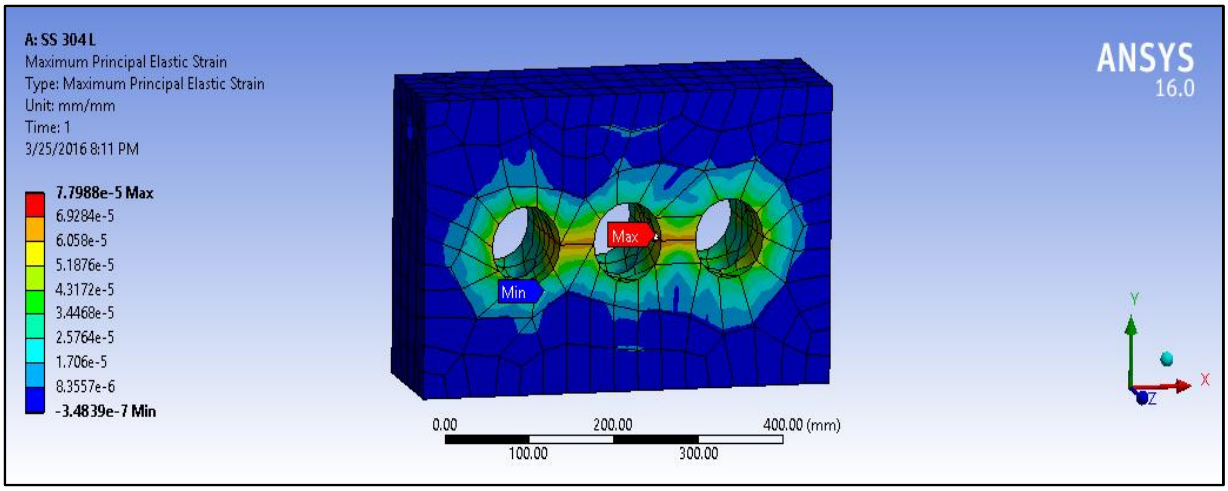


Fig 4.8: Max Principal Elastic strain for SS 304L

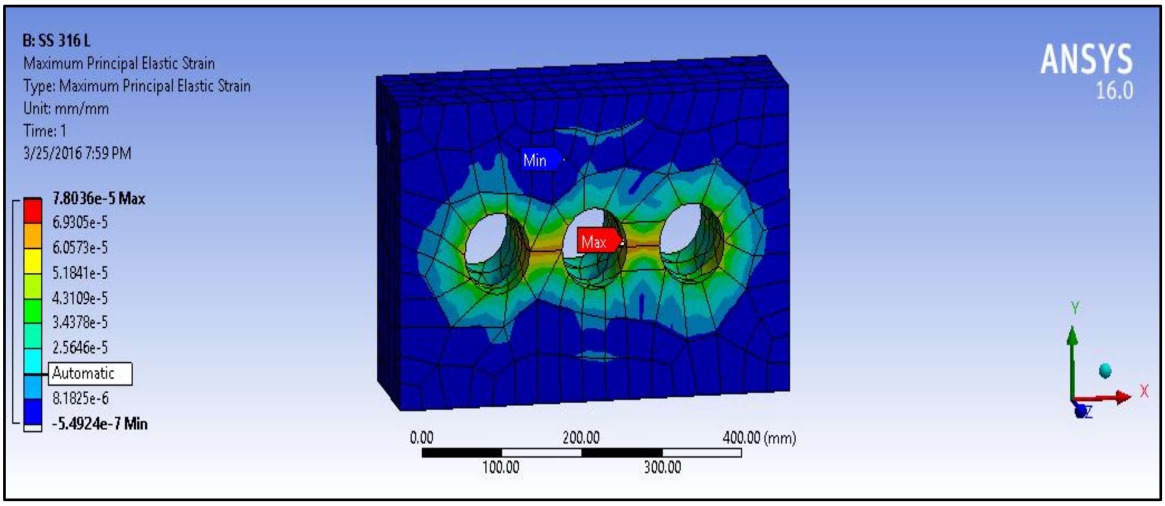


Fig 4.9: Max Principal Elastic strain for SS 316L

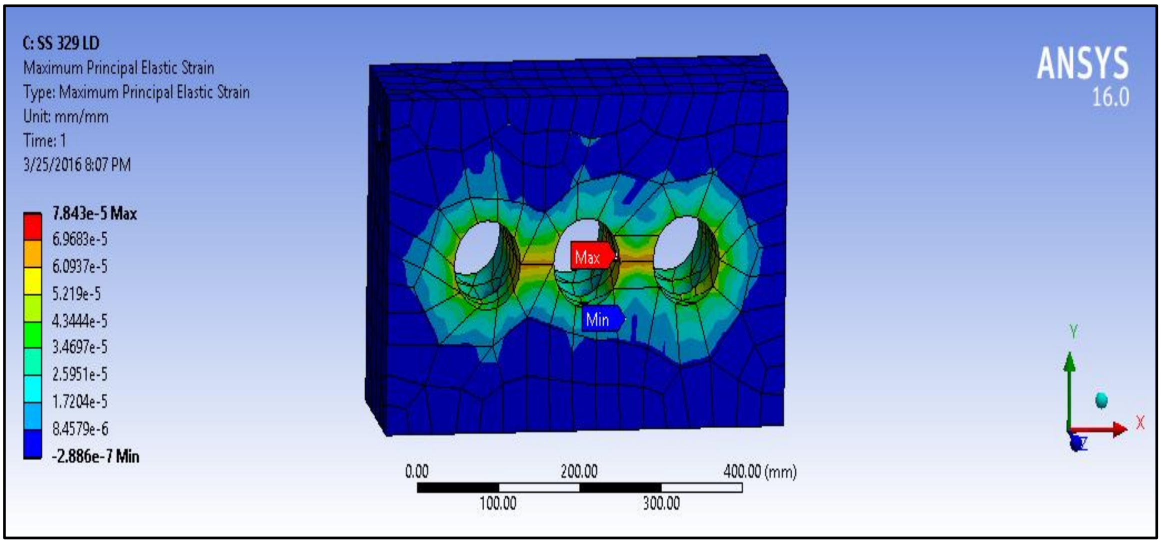


Fig 4.10: Max Principal Elastic strain for SS 329LD

❖ <u>Maximum Principal Stress</u>

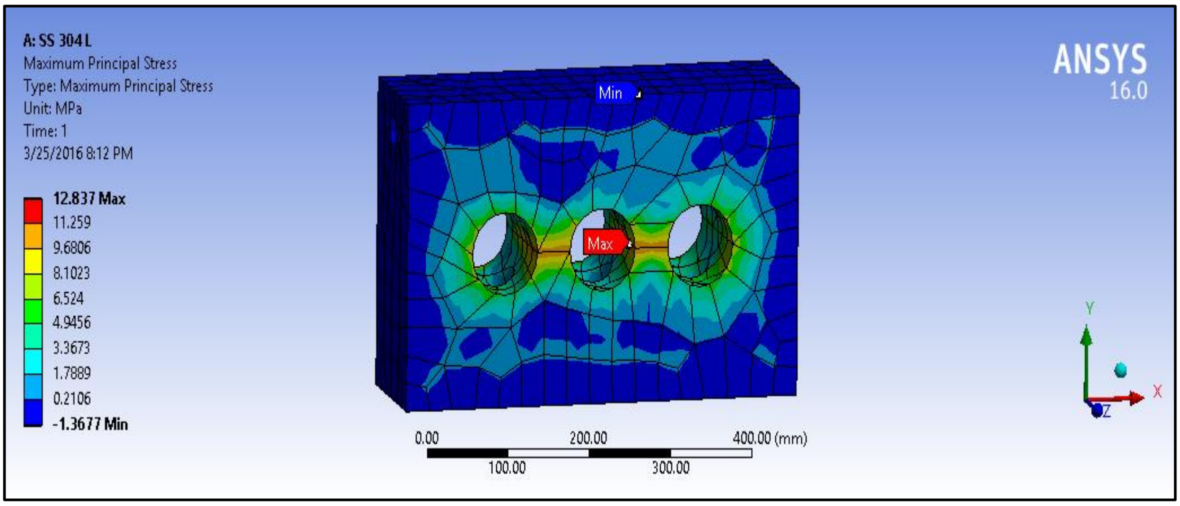


Fig 4.11: Maximum Principal Stress for SS 304L

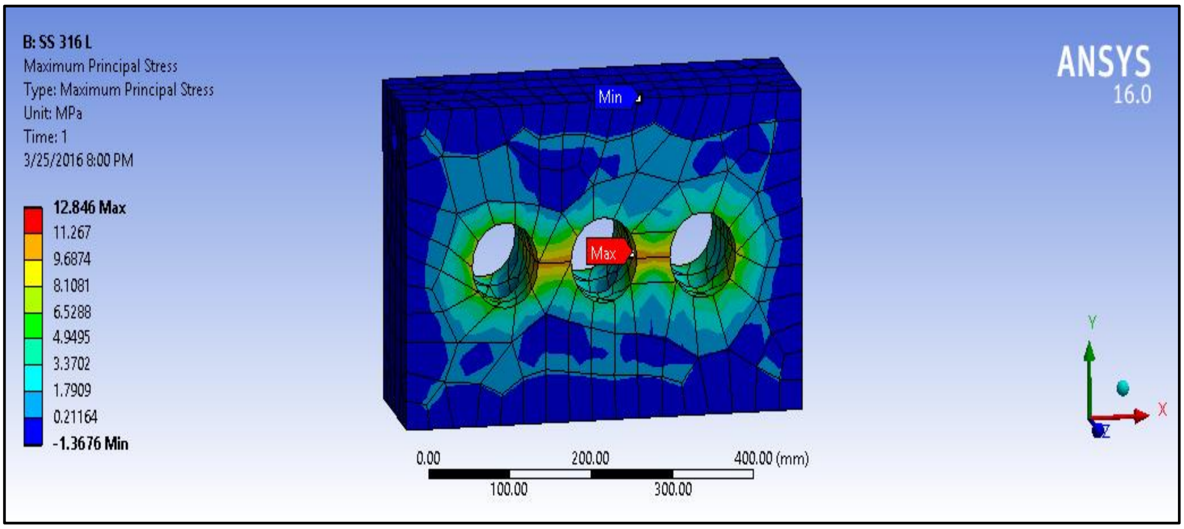


Fig 4.12: Maximum Principal Stress for SS 316L

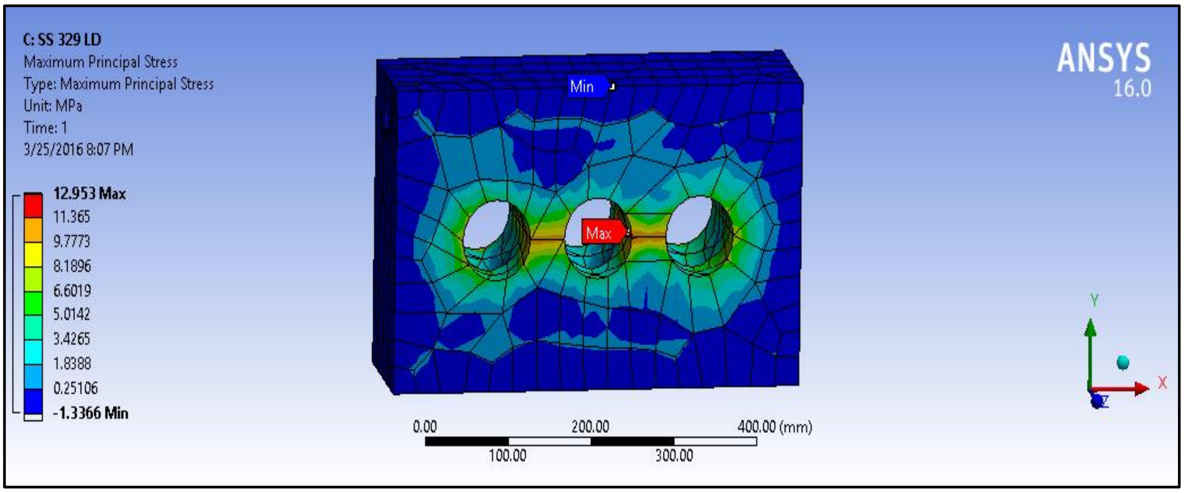


Fig 4.13: Maximum Principal Stress for SS 329LD

Total Deformation

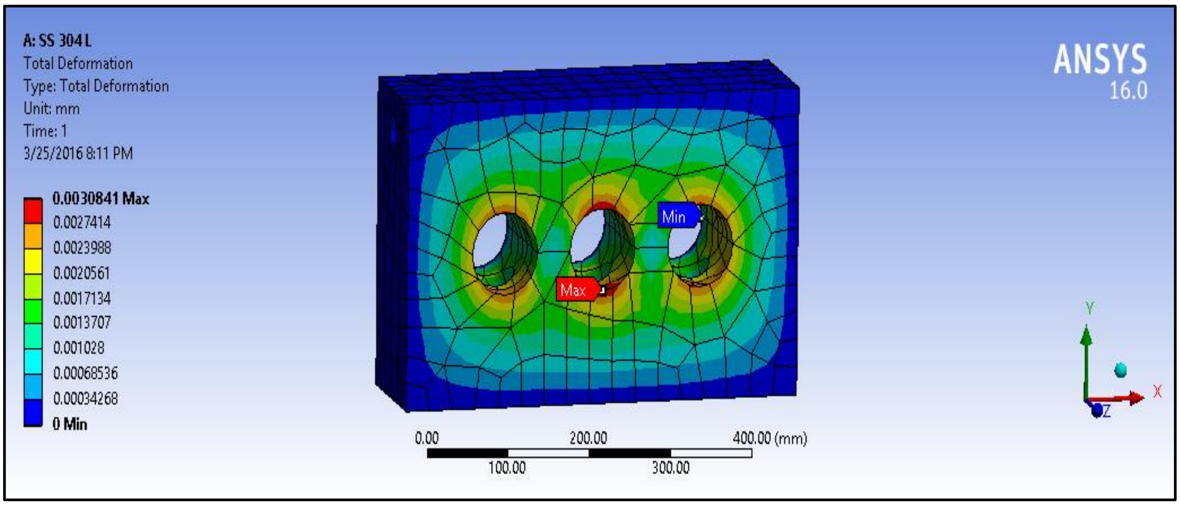


Fig 4.14: Total Deformation for SS 304L

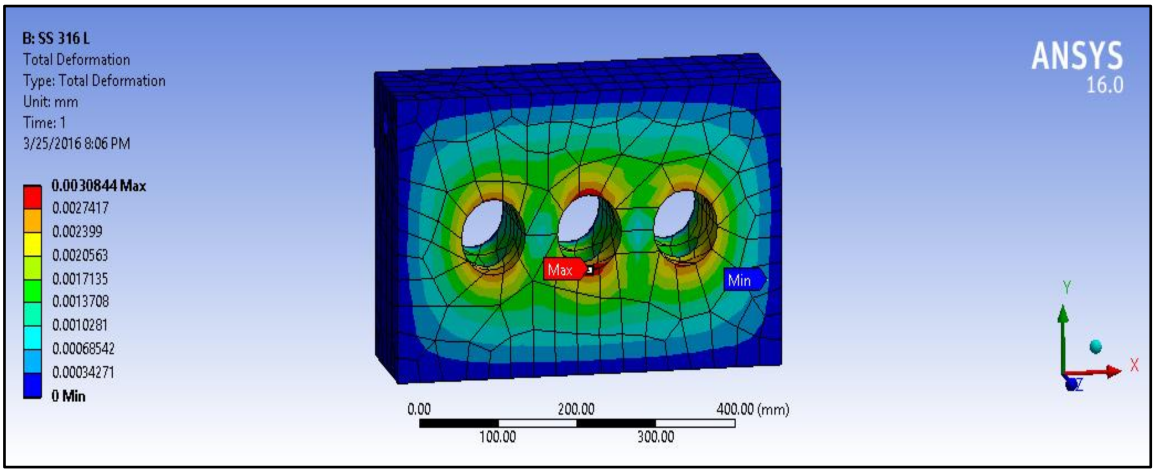


Fig 4.15: Total Deformation for SS 316L

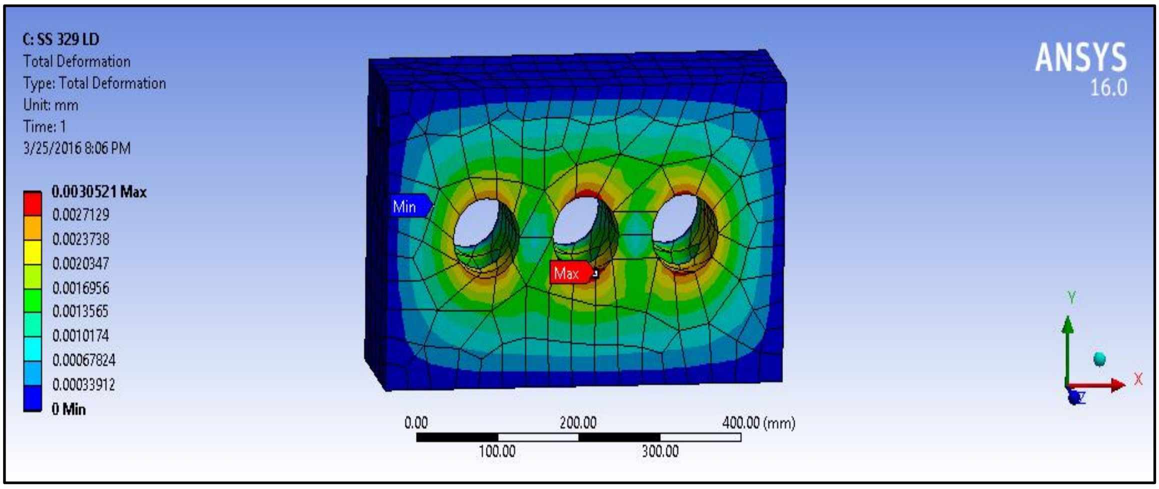


Fig 4.16: Total Deformation for SS 329LD

5. RESULTS

From the above results obtained through the analysis carried out by the ANSYS software had been summarized as follows:

Table 5.1 Results summary

Results for Stainless Steel Alloys			
	SS 304 L	SS 316 L	SS 329 LD
Maximum Von-Mises stress (MPa)	20.028	20.118	20.51
Max Principal Elastic strain (x 10-5 mm/mm)	7.7988	7.803	7.843
Max Principal Stress (MPa)	12.837	12.846	12.953
Total Deformation (x 10-5 mm)	30841	30844	30521
Proof Yield Strength 0.2% (MPa)	170	170	450
Factor of Safety	2	2	2
Allowable stress (MPa)	85	85	225
Stress Ratio (Max Equivalent stress / Allowable stress)	0.236	0.237	0.091
Stress Ratio (%)	23.6	23.7	9.1
Stress Margin	3.24	3.23	9.97

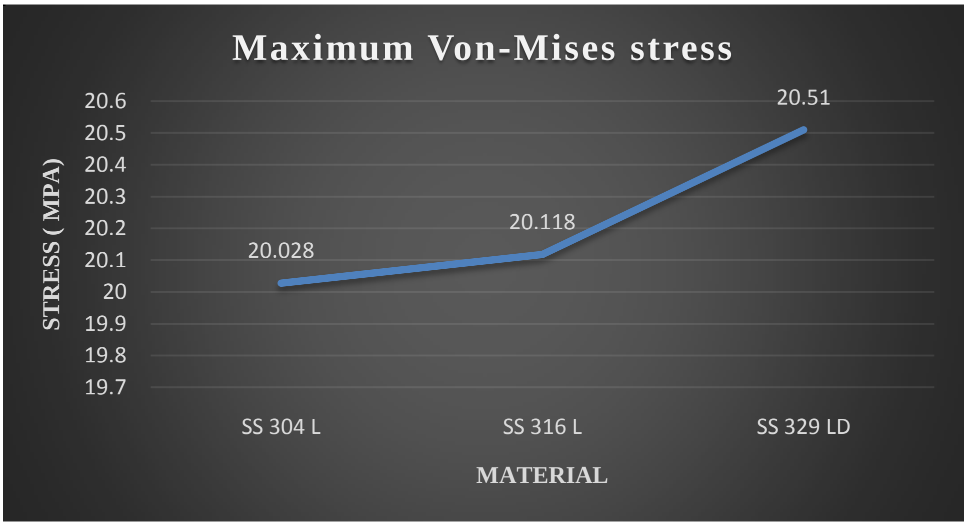


Fig 5.1: Max Von-Mises Stress

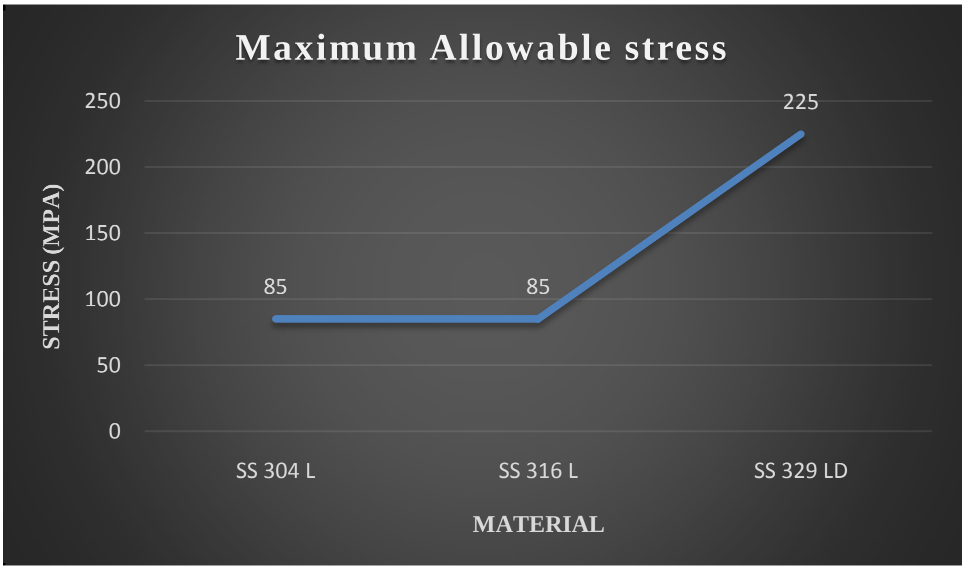


Fig 5.2: Max Allowable Stress

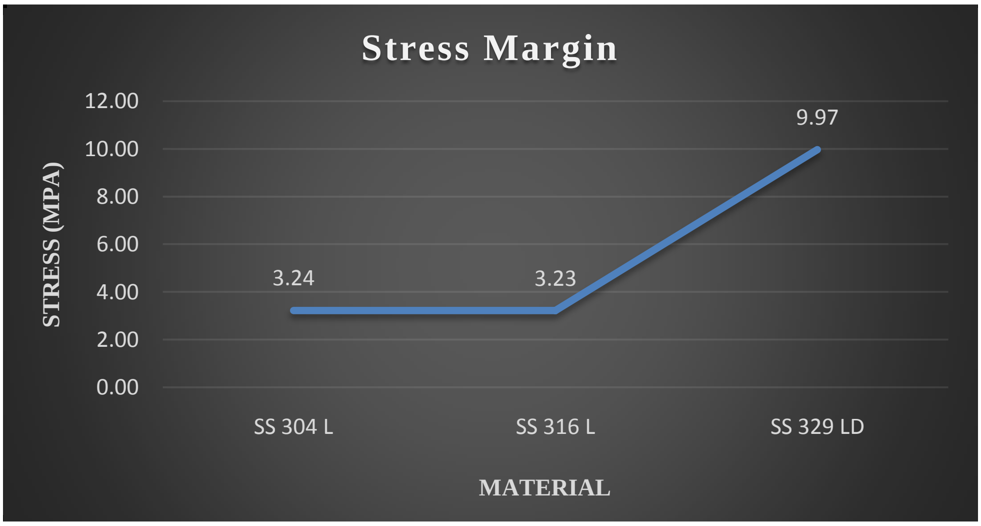


Fig 5.3: Stress Margin

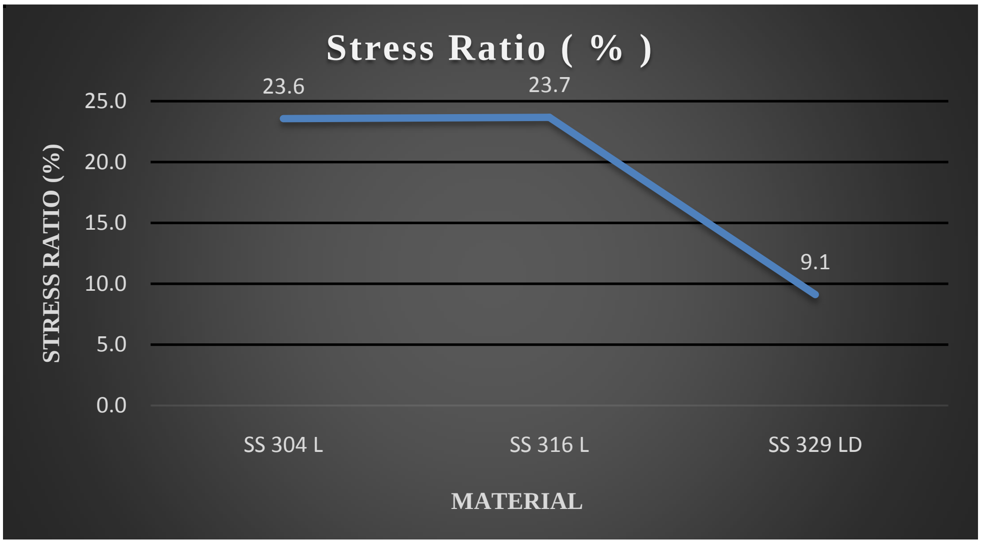


Fig 5.4: Stress Ratio (%)

The graph plotted above from the results obtained with the ANSYS software stated that:

a) **Higher Proof Yield strength** of SS 329 LD as compared with the SS 304L and SS 316L results with the higher Equivalent Von-Mises Stress and Allowable stress.

b) **Stress Ratio** percentage calculated for SS 304 L, SS 316 L and SS 329 LD materials were **23.6, 23.7 and 9.1** respectively. This stated that, as compared with **23%** of the stresses had been consumed for SS 304L and SS 316L material , only **9 %** stresses had been consumed for SS 329 LD. Hence, it signified that SS 329 LD material has ample of scope for increasing the stress percentage.

c) **Stress margin** calculated for SS 304 L, SS 316 L and SS 329 LD materials were **3.23, 3.24 and 9.97** respectively. Hence, for SS 329 LD almost **10 times** stresses can be increased on the structure made of this material, whereas only **3 times** stresses can be increased on SS 304 L and SS 316 L.

d) Higher percentage of Total Deformation, Higher Principal Elastic Strain and Higher Principal stress of material SS 329 LD results with the sustenance of the structure with **longer life span**.

e) Carbon Percentage of the SS 304 L and SS 316 L is 0.03 % whereas for SS 329 LD is less than 0.03 %. This showed that the material is less corrosive or **higher corrosion resistance** for the adverse environment like with the presence of chlorine content / acidic character of the contact material.

6. CONCLUSION

The above results shows that the material selected (SS 329LD) could be used as the material composition for manufacturing the Compression Head of Homogenizer as it is having more superior properties than existing used grades of SS material i.e. SS 304 L and SS 316L.

Advantages of using this SS 329 LD grade of material:

1) The presence of Ni and Molybdenum for resource saving in super duplex stainless steel leads to excellent pitting corrosion, crevice corrosion, inter granular corrosion and stress corrosion cracking resistance.
2) Higher Proof strength which leads to reduced section thickness, reduced weight. Hence, it could be used in Food Processing industry, manufacturing industry, chemical industry, real estates, refineries, automotive industry etc.
3) Less than 0.03% Carbon percentage hence it is having higher Corrosion resistance properties.
4) Existence of improved percentage of Nitrogen leads to more strength.
5) SS 329 LD has higher tensile strength and Yield strength. Therefore, it has better sustenance to cater higher loads with usual and unusual sinusoidal forces acting on it.
6) Better ferritic structure:
   i. It leads to the improved characteristics of Weldability to thicker sections.
   ii. It improves the properties for Toughness and hence stability of material typically down to minus 50 deg C, stretching to minus 80 deg C.

7. FUTURE SCOPE

As per the results obtained above, following inference has been obtained:

- Because of higher corrosion resistance properties it could be efficiently used in Food Manufacturing Industries where the food content remains in direct contact with the metal content. Hence, it can prove to be a revolution in this sector and can bring a drastic change in all those industries where the problem of corrosion becomes a challenge for the sustenance and existence of material for a prolong period of time.
- Other grades of SS Material SS 441 and SS 420 N1 could also be tested and analyzed as well because these grades also have good resistance to crevice corrosion.

- It can also be used in structural building material and underground pipelines for sewage and effluent, chimneys etc. where high life span is required otherwise they may create disaster to life and property.

REFERENCES

[1] Mr. Pradeep Mani Tripathi, Mr. Satya Prakash, Mr. Rahul Singh, Mr. Satish Kumar Dwivedi, April 2014, "Thermal Analysis on Cylinder Head of SI Engine Using FEM" *International Journal of Scientific Engineering and Research (IJSER)*, Vol. 2 Issue 4, ISSN: 2347-3878.

[2] Rabinarayan Sethi, S.K.Senapati and D.R.K. Parhi, September 2014 "Analysis of Crack in Structures using Finite Element Method" *Global Science and Technology Journal*, Volume 2, No. 2.

[3] Bhumesh J. Bagde, Laukik P. Raut, May 2013 "Finite Element Analysis of Single Cylinder Engine Crank Shaft" *International Journal of Advances in Engineering and Technology (IJAET)*, ISSN: 2231-1963.

[4] Abdul Halim ABDULLAH and Mitsugu TODO, Feb 2015 "Prediction of Damage Formation in Total Hip Arthroplasty using Finite Element Method" *Engineering Sciences Reports, Kyushu University,* Vol. 36, No.2.

[5] Danas Sutula, Pierre Kerfriden and Stephane P.A. Bordas, July 20-25, 2014 "Global Energy Minimization for Multi-Crack Growth in Linear Elastic Fracture using the Extended Finite Element Method" *European Conference on Computational Fluid Dynamics (ECFD VI)*, Barcelona, Spain.

[6] Camelia Pinca Bretotean, 2011 "The Finite Element analysis of a Cylinder Head of a Spark Ignition Engine" *Annals of Faculty Engineering Hunedoara, International Journal of Engineering Tome IX*, ISSN: 1584-2673.

[7] Sreeraj Nair K., Kiran Robert and Shamnadh M., 2014 "Static Stress Analysis of IC Engine Cylinder Head" *International Review of Applied Engineering Research*, Vol. 4, Number 2, ISSN 2248-9967.

[8] Shixiong Li, Jinlong Mao, Shumao Wang, 2004 '' Cylinder Head FEM Analysis and its Improvement", *College of Engineering, China Agricultural University*.

[9] Kutlay Aksoz, September 2014 "Dynamic Analysis of Hydraulic Cylinder" *Graduate School of Natural and Applied Sciences*, IZMIR.

[10] Michael Singer, Torsten Johne, October 1-3, 2013 "Design of Pump Casings: Guidelines for a Systematic Evaluation of Centrifugal Pump Pressure Boundary Failure Modes and their Mechanisms" *29th International Pump Users Symposium, Houston, Texas*.

[11] Poonam Dhankhar, May, 2014 "Homogenization Fundamentals" *IOSR Journal of Engineering (IOSRJEN)*, Vol. 04, Issue 05, ISSN: 2250-3021.\

[12] Gosta Bylund, 1995 "Tetra Pak Processing Systems handbook" ABS-221 86 Lund, Sweden.

[14] Evgeny Barkanov 2001 "Introduction to the Finite Element Method" Institute of Materials and Structures.

[15] Mahendra G. Rathi, Nilesh J. Jakhade, 2014 "An Overview of Forging processes with their defects" International Journal of Scientific and Research Publications, Vol. 04, Issue 06, ISSN: 2250-3153.