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Using finite analysis to predict fatigue behavior of dissimilar welded specimen

Senior project report
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CHAPTER 1

Fatigue

1-1 Fatigue :

1.1.1 Introduction :

So far we have examined materials behavior under slowly rising load (the tensile test) and under impact loading (the impact test). We learned from the first test that a smooth specimen fails by overloading if the statistically applied stress exceeds the tensile strength of the material. However, failure can still occur at a stress level less than the yield strength (σ_y) if the applied stress is fluctuating with time. Failure caused by cyclic loading is termed fatigue and the number of total loading cycles applied until fracture is called the fatigue-life. The majority of engineering components experience some sort of load fluctuations and it has been estimated that fatigue is responsible for more than 70% of all engineering materials failures. Therefore, engineers should be aware of this type of failure and know how to design against it.

1.1.2 Where Fatigue is important? :

Fatigue failure consists of two stages: crack initiating and crack propagation until total fracture. For machine components containing no pre-existing cracks, the majority of fatigue life is spent in initiating or starting fatigue cracks and the fatigue process is described as initiation-controlled. Examples of these include crank shafts, gear teeth, and rotating shafts or axles. On the other hand, large structures or welded parts almost always contain pre-existing cracks such as in bridges, ships, aircraft fuselage, and pressure vessels. In such structures, the majority of fatigue life is spent in growing a pre-existing crack to a critical size and then to final fracture. The fatigue process in this case is described propagation-controlled. In this laboratory session we will be concerned only with fatigue testing of un-cracked specimens where most of fatigue life is spent in the initiation stage.

Engineering structures and components often contain stress concentrations such as notches. Fatigue cracks almost always start at regions of high stress concentrations. For example, Figure 5.1 shows a fatigue crack starting from a keyhole in a rotating shaft. Fracture surfaces of components failed by fatigue are usually flat and perpendicular to the applied stress and often show features called beachmark ridges as shown in Figure 5.1. These marks are positive indication for fatigue failure and they represent the crack fronts during loading. Furthermore, fatigue

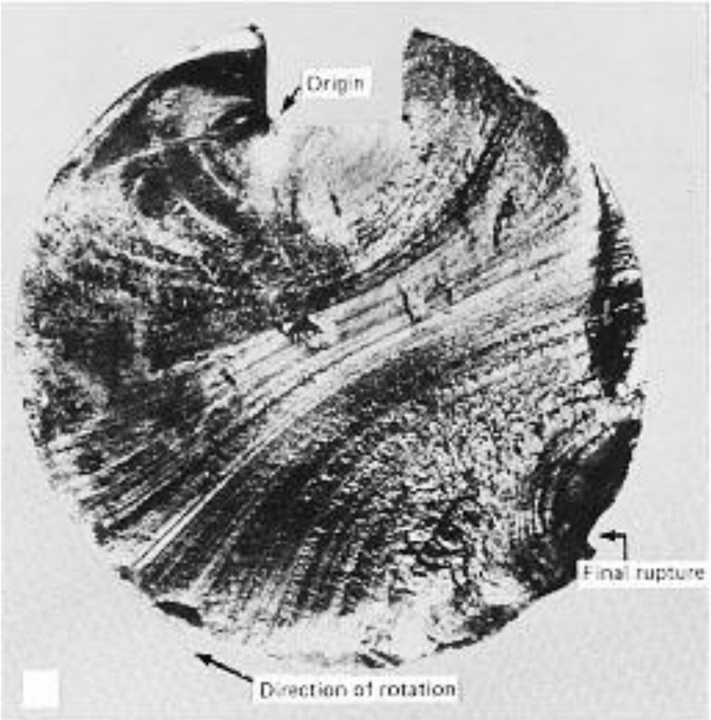


Figure 1.1: a shaft containing a keyhole failed due to fatigue

1.1.3 Fatigue Test :

A method for determining the behavior of materials under fluctuating loads. A specified mean load (which may be zero) and an alternating load are applied to a specimen and the number of cycles required to produce failure (fatigue life) is recorded. Generally, the test is repeated with identical specimens and various fluctuating loads. Loads may be applied axially, in torsion, or in flexure. Depending on amplitude of the mean and cyclic load, net stress in the specimen may be in one direction through the loading cycle, or may reverse direction. Data from fatigue testing often are presented in an S-N diagram which is a plot of the number of cycles required to cause failure in a specimen against the amplitude of the cyclical stress developed. The cyclical stress represented may be Stress Amplitude, maximum stress or minimum stress. Each curve in the diagram represents a constant mean stress. Most fatigue tests are conducted in flexure, rotating beam, or vibratory type machines. Fatigue testing is generally discussed in "Manual on Fatigue Testing," ASTM STP 91-A, and "Mechanical Testing of Materials," A.J. Fenner, Philosophical Library, Inc. ASTM D-671 details a standard procedure for fatigue testing of plastics in flexure.

failure is brittle in nature and does not involve gross plastic deformation even in metals that behave in a ductile manner under static loading. Hence, fatigue failure occurs suddenly and can cause catastrophic consequences.

1.1.4 Test Description :

You can perform a simple fatigue test with your hands. Take a thin wire and bend it back and forth many times, the wire will break after a number of cycles depending on the stress level. Increasing the applied load will reduce the number of cycles required to break the wire and you can test this by increasing the displacement of your hands during bending. However, for good testing we need more accurate control of the cyclic load and this can be done by a rotating bending machine, shown in Figure 5.2. In this machine, a cylindrical smooth specimen is mounted and loaded from both ends using rotating chucks (see figure 5.3). A weight is suspended from one side of the specimen to vary the bending stresses experienced by the specimen surface. Initially, the specimen will experience tensile stresses at its top surface and compressive stresses at its bottom. As the specimen rotates 180 degrees, the stresses will be reversed and the top will be under compressive stresses while the bottom will be under tensile stresses. When the specimen completes one full rotation, the specimen surfaces would have experienced one full loading cycle. The maximum bending stress acting on the specimen surface is given by

Figure 1.2: Fatigue rotating bending machine

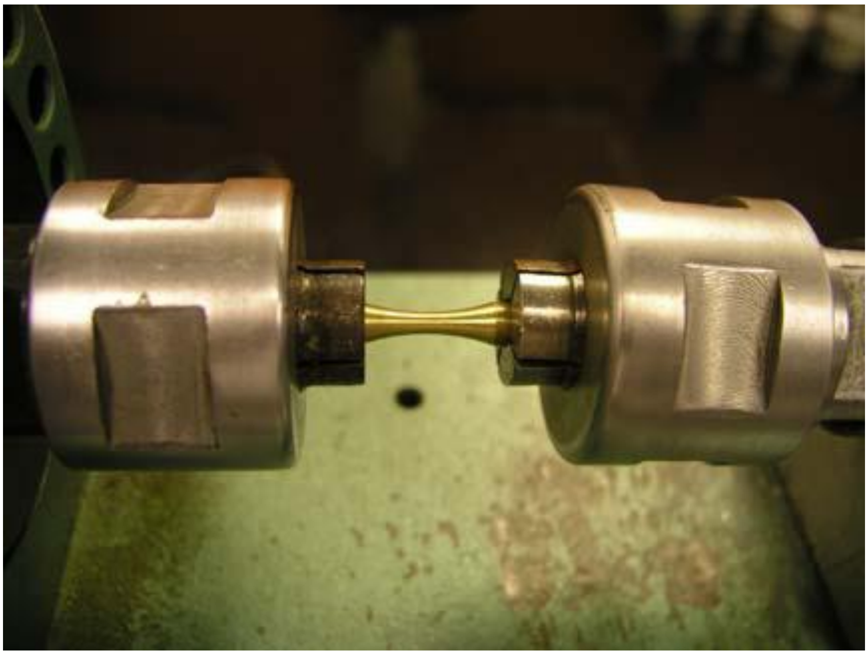


Figure 1.3: Mounted fatigue specimen

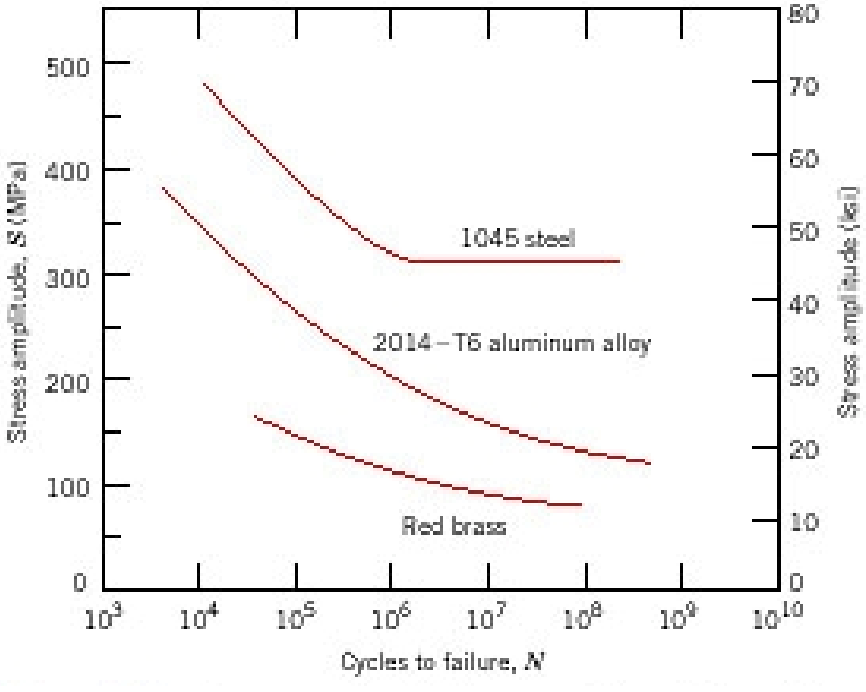
$\sigma = 32\,\mathbf{M}/\pi\mathbf{d}^3$ where, σ = the maximum bending stress
M = the bending moment at the specimen cross-section (weight*distance) d = specimen diameter.

The same test is repeated for many specimens each conducted at different stress level and the number of cycles it would take to fail is recorded. The S-N curve is a plot of the applied stresses versus the logarithm of the number of cycles to failure (N) for each specimen. The ASTM standards E466 and E468 are to be consulted for further details of the test.

1.1.5 <u>The S-N Curve</u>

Figure 3.4 shows the S-N curves for three metallic alloys: steel, aluminum, and brass. Note that as the stress is decreased, the fatigue life is increased for all alloys. However, only the steel alloy shows a stress level below which fatigue failure will not take place. This stress level is a property of the material and called the endurance limit or the fatigue limit and can be observed only in the S-N curves for steel alloys. For example, a cyclic stress of 350 MPa will cause fatigue failure in a part made out of 2014-T6 aluminum alloy in just 10^4 cycles while a part made from 1045 steel will not fail until approximately 4x10^5 cycles. Note that the fatigue limit for the 1045 steel is around 310 MPa. Hence, to design against fatigue failure for a part made from 1045 steel, we must make sure that the stress amplitude must be less than 310 MPa.

It should be noted that the S-N curve is very sensitive to many variables including the mean stress, the presence of notches, testing temperature, surface-finish of the specimen, surface hardness, and the corrosivity of the environment. Care must be taken in test preparation to simulate the actual service conditions to get meaningful data.



1.1.6 Test Procedure

Because fatigue testing is time consuming and requires a large number of specimens to generate an S-N curve, we will limit testing to few samples as a demonstration. The following procedure is followed:

- Measure the dimension of the steel specimen provided to you by your instructor.
- Write down the surface finish of the specimen (ask your instructor).
- Mount the specimen in the rotating bending machine.
- Record the weight and measure the distance needed to calculate the bending moment.
- Zero the counter.
- Start the machine and wait until the specimen is broken.
- Write down the number of cycles to failure.
- Repeat the test with different weights.
- Observe the fractured specimen in the optical and in the scanning electron microscope.
- Plot the S-N data in the full S-N curve for the same material.
- Note and discuss any disagreement between your data and the supplied S-N curve.

CHAPTER 2

2.1 Materials :

We have used three materials in this project:

- **Stainless steal 304**
- **Plain carbon steal**
- **Electrode E309 and E316**

2.1 Stainless steel 304 :

2.1.1 Background :

Grade 304 is the standard "18/8" stainless; it is the most versatile and most widely used stainless steel, available in a wider range of products, forms and finishes than any other. It has excellent forming and welding characteristics. The balanced austenitic structure of Grade 304 enables it to be severely deep drawn without intermediate annealing, which has made this grade dominant in the manufacture of drawn stainless parts such as sinks, hollow-ware and saucepans. For these applications it is common to use special "304DDQ" (Deep Drawing Quality) variants. Grade 304 is readily brake or roll formed into a variety of components for applications in the industrial, architectural, and transportation fields. Grade 304 also has outstanding welding characteristics. Post-weld annealing is not required when welding thin sections.

Grade 304L, the low carbon version of 304, does not require post-weld annealing and so is extensively used in heavy gauge components (over about 6mm). Grade 304H with its higher carbon content finds application at elevated temperatures. The austenitic structure also gives these grades excellent toughness, even down to cryogenic temperatures.

2.1.2 Key Properties :

These properties are specified for flat rolled product (plate, sheet and coil) in ASTM A240/A240M. Similar but not necessarily identical properties are specified for other products such as pipe and bar in their respective specifications.

2.1.3 Composition :

Typical compositional ranges for grade 304 stainless steels are given in table 1.

Table 2-1: Composition ranges for 304 grade stainless steel

Grade		C	Mn	Si	P	S	Cr	Mo	Ni	N
304	min.	-	-	-	-	-	18.0	-	8.0	-
	max.	0.08	2.0	0.75	0.045	0.030	20.0		10.5	0.10
304L	min.	-	-	-	-	-	18.0	-	8.0	-
	max.	0.030	2.0	0.75	0.045	0.030	20.0		12.0	0.10
304H	min.	0.04	-	-	-	-	18.0	-	8.0	-
	max.	0.10	2.0	0.75	0.045	0.030	20.0		10.5	

2.1.4 Mechanical Properties :

Typical mechanical properties for grade 304 stainless steels are given in table 2.

Table2- 2: Mechanical properties of 304 grade stainless steel

Grade	Tensile Strength (MPa) min	Yield Strength 0.2% Proof (MPa) min	Elongation (% in 50mm) min	Hardness	
				Rockwell B (HR B) max	Brinell (HB) max
304	515	205	40	92	201
304L	485	170	40	92	201
304H	515	205	40	92	201
304H also has a requirement for a grain size of ASTM No 7 or coarser.					

2.1.5 Physical Properties :

Typical physical properties for annealed grade 304 stainless steels are given in table 3.

Table 2-3: Physical properties of 304 grade stainless steel in the annealed condition

Grade	Density (kg/m^3)	Elastic Modulus (GPa)	Mean Coefficient of Thermal Expansion (µm/m/°C)			Thermal Conductivity (W/m.K)		Specific Heat 0-100°C (J/kg.K)	Electrical Resistivity (nΩ.m)
			0-100°C	0-315°C	0-538°C	at 100°C	at 500°C		
304/L/H	8000	193	17.2	17.8	18.4	16.2	21.5	500	720

2.1.6 Grade Specification Comparison :

Approximate grade comparisons for 304 stainless steels are given in table 4.

Table 2-4: Grade specifications for 304 grade stainless steel

Grade	UNS No	Old British		Euronorm		Swedish	Japanese JIS
		BS	En	No	Name	SS	
304	S30400	304S31	58E	1.4301	X5CrNi18-10	2332	SUS 304
304L	S30403	304S11	-	1.4306	X2CrNi19-11	2352	SUS 304L
304H	S30409	304S51	-	1.4948	X6CrNi18-11	-	-
These comparisons are approximate only. The list is intended as a comparison of functionally similar materials **not** as a schedule of contractual equivalents. If exact equivalents are needed original specifications must be consulted.							

2.1.7 Possible Alternative Grades :

Possible alternative grades to grade 304 stainless steels are given in table 5.

Table 2-5: Possible alternative grades to 304 grade stainless steel

Grade	Why it might be chosen instead of 304
301L	A higher work hardening rate grade is required for certain roll formed or stretch formed components.
302HQ	Lower work hardening rate is needed for cold forging of screws, bolts and rivets.
303	Higher machinability needed, and the lower corrosion resistance, formability and weldability are acceptable.
316	Higher resistance to pitting and crevice corrosion is required, in chloride environments
321	Better resistance to temperatures of around 600-900°C is needed…321 has higher hot strength.
3CR12	A lower cost is required, and the reduced corrosion resistance and resulting discolouration are acceptable.
430	A lower cost is required, and the reduced corrosion resistance and fabrication characteristics are acceptable.

2.1.8 Corrosion Resistance :

Excellent in a wide range of atmospheric environments and many corrosive media. Subject to pitting and crevice corrosion in warm chloride environments, and to stress corrosion cracking above about 60°C. Considered resistant to potable water with up to about 200mg/L chlorides at ambient temperatures, reducing to about 150mg/L at 60°C.

2.1.9 Heat Resistance :

Good oxidation resistance in intermittent service to 870°C and in continuous service to 925°C. Continuous use of 304 in the 425-860°C range is not recommended if subsequent aqueous corrosion resistance is important. Grade 304L is more resistant to carbide precipitation and can be heated into the above temperature range.

Grade 304H has higher strength at elevated temperatures so is often used for structural and pressure-containing applications at temperatures above about 500°C and up to about 800°C. 304H will become sensitised in the temperature range of 425-860°C; this is not a problem for high temperature applications, but will result in reduced aqueous corrosion resistance.

2.1.10 Heat Treatment :

Solution Treatment (Annealing) - Heat to 1010-1120°C and cool rapidly. These grades cannot be hardened by thermal treatment.

2.1.11 Welding :

Excellent weldability by all standard fusion methods, both with and without filler metals. AS 1554.6 pre-qualifies welding of 304 with Grade 308 and 304L with 308L rods or electrodes (and with their high silicon equivalents). Heavy welded sections in Grade 304 may require post-weld annealing for maximum corrosion resistance. This is not required for Grade 304L. Grade 321 may also be used as an alternative to 304 if heavy section welding is required and post-weld heat treatment is not possible.

2.1.12 Machining :

A "Ugima" improved machinability version of grade 304 is available in bar products. "Ugima" machines significantly better than standard 304 or 304L, giving higher machining rates and lower tool wear in many operations.

2.1.13 Dual Certification :

It is common for 304 and 304L to be stocked in "Dual Certified" form, particularly in plate and pipe. These items have chemical and mechanical properties complying with both 304 and 304L specifications. Such dual certified product does not meet 304H specifications and may be unacceptable for high temperature applications

2.1.14 Applications :

Typical applications include:

- Food processing equipment, particularly in beer brewing, milk processing & wine making.
- Kitchen benches, sinks, troughs, equipment and appliances
- Architectural panelling, railings & trim
- Chemical containers, including for transport
- Heat Exchangers
- Woven or welded screens for mining, quarrying & water filtration
- Threaded fasteners
- Springs

2.2 Plain Steel :

Carbon steel, also called plain carbon steel, is a malleable, iron-based metal containing carbon, small amounts of manganese, and other elements that are inherently present. Steels can either be cast to shape or wrought into various mill forms from which finished parts are formed, machined, forged, stamped, or otherwise shaped.

Cast steels are poured to near-final shape in sand molds. The castings are then heat treated to achieve specified properties and machined to required dimensions.

Wrought steel undergoes two operations. First, it is either poured into ingots or strand cast. Then, the metal is reheated and hot rolled into the finished, wrought form. Hot-rolled steel is characterized by a scaled surface and a decarburized skin. Hot-rolled bars may be subsequently finished in a two-part process. First, acid pickling or shot blasting removes scale. Then, cold drawing through a die and restraightening improves surface properties and strength. Hot-rolled steel may also be cold finished by metal-removal processes such as turning or grinding. Wrought steel can be subsequently heat treated to improve machinability or to adjust mechanical properties.

Carbon steels may be specified by chemical composition, mechanical properties, method of deoxidation, or thermal treatment (and the resulting microstructure).

2.2.1 Composition :

Wrought steels are most often specified by composition. No single element controls the characteristics of a steel; rather, the combined effects of several elements influence hardness, machinability, corrosion resistance, tensile strength, deoxidation of the solidifying metal, and microstructure of the solidified metal.

Effects of carbon, the principal hardening and strengthening element in steel, include increased hardness and strength and decreased weldability and ductility. For plain carbon steels, about 0.2 to 0.25% C provides the best machinability. Above and below this level, machinability is generally lower for hot-rolled steels.

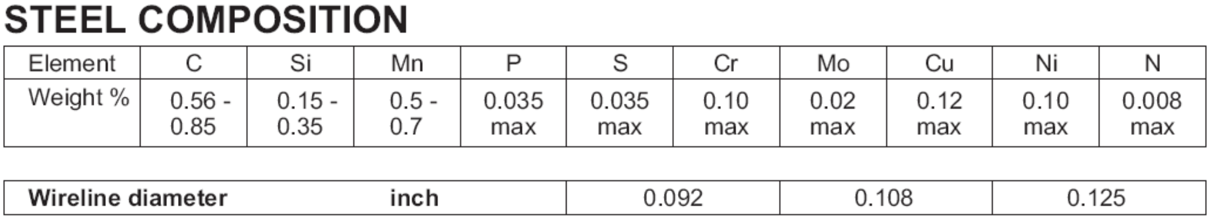
Standard wrought-steel compositions (for both carbon and alloy steels) are designated by an AISI or SAE four-digit code, the last two digits of which indicate the nominal carbon content. The carbon-steel grades are:

The letter "L" between the second and third digits indicates a leaded steel; "B" indicates a boron steel. Cast-carbon steels are usually specified by grade, such as A, B, or C. The A grade (also LCA, WCA, AN, AQ, etc.) contains 0.25% C and 0.70% Mn maximum. B-grade steels contain 0.30% C and 1.00% Mn, and the C-grade steels contain 0.25% C and 1.20% Mn. These carbon and manganese contents are designed to provide good strength, toughness, and weldability. Cast carbon steels are specified to ASTM A27, A216, A352, or A487.

Microalloying technology has created a new category of steels, positioned both in cost and in performance between carbon steels and the alloy grades. These in-between steels consist of conventional carbon steels to which minute quantities of alloying elements -- usually less than 0.5% -- are added in the steelmaking process to improve mechanical properties. Strength and hardness are increased significantly.

Any base-grade steel can be microalloyed, but the technique was first used in sheet steel a number of years ago. More recently, microalloying has been applied to bar products to eliminate the need for heat-treating operations after parts are forged. Automotive and truck applications include connecting rods, blower shafts, stabilizer bars, U-bolts, and universal joints. Other uses are sucker rods for oil wells and anchor bolts for the construction industry.

Table 2-6 : steel composition .



STEEL COMPOSITION

Element	C	Si	Mn	P	S	Cr	Mo	Cu	Ni	N
Weight %	0.56 - 0.85	0.15 - 0.35	0.5 - 0.7	0.035 max	0.035 max	0.10 max	0.02 max	0.12 max	0.10 max	0.008 max

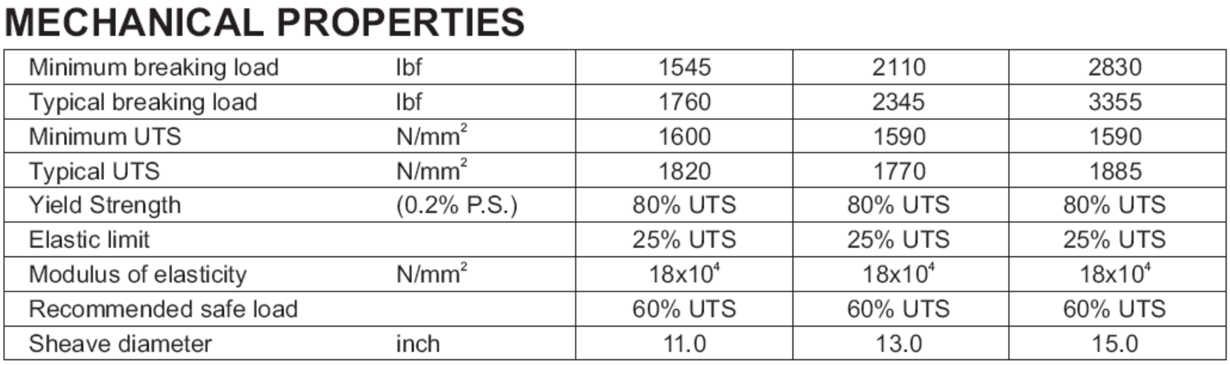
Wireline diameter	**inch**	0.092	0.108	0.125

2.2.2 Mechanical properties :

Cast and wrought products are often specified to meet distinct mechanical requirements in structural applications where forming and machining are not extensive. When steels are specified by mechanical properties only, the producer is free to adjust the analysis of the steel (within limits) to obtain the required properties. Properties may vary with cross section and part size.

Mechanical tests are usually specified under one of two conditions: mechanical test requirements and no chemical limits on any element, or mechanical test requirements and chemical limits on one or more elements, provided that such requirements are technologically compatible.

Table 2-7:Mechanical Properties



MECHANICAL PROPERTIES

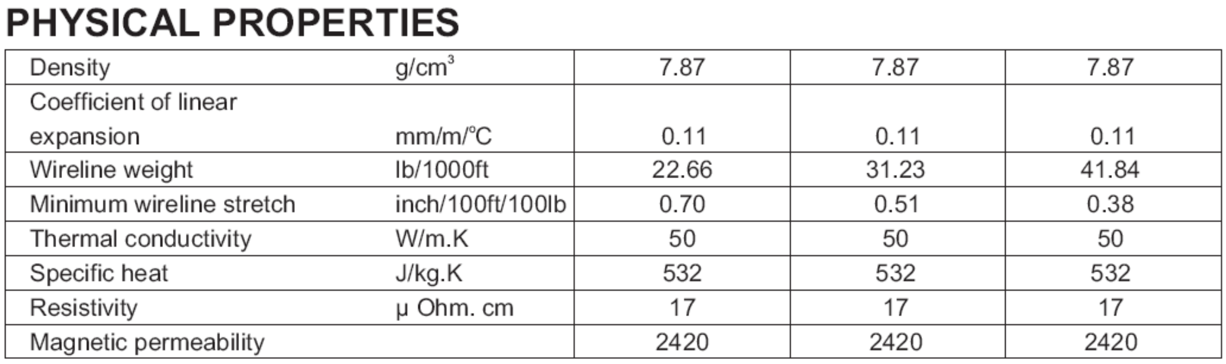
Minimum breaking load	lbf	1545	2110	2830
Typical breaking load	lbf	1760	2345	3355
Minimum UTS	N/mm^2	1600	1590	1590
Typical UTS	N/mm^2	1820	1770	1885
Yield Strength	(0.2% P.S.)	80% UTS	80% UTS	80% UTS
Elastic limit		25% UTS	25% UTS	25% UTS
Modulus of elasticity	N/mm^2	18x10^4	18x10^4	18x10^4
Recommended safe load		60% UTS	60% UTS	60% UTS
Sheave diameter	inch	11.0	13.0	15.0

2.2.3 Microstructure :

The microstructure of carbon and alloy steels in the as-rolled or as-cast condition generally consists of ferrite and pearlite. This basic structure can be altered significantly by various heat treatments or by rolling techniques. A spheroidized annealed structure would consist of spheroids of iron and alloy carbides dispersed in a ferrite matrix for low hardness and maximum ductility, as might be required for cold-forming operations. Quenching and tempering provide the optimum combination of mechanical properties and toughness obtainable from steel. Grain size can also be an important aspect of the microstructure. Toughness of fine-grained steels is generally greater than that of coarse-grained steels.

2.2.4 Physical properties :

Table 2-8 : physical properties

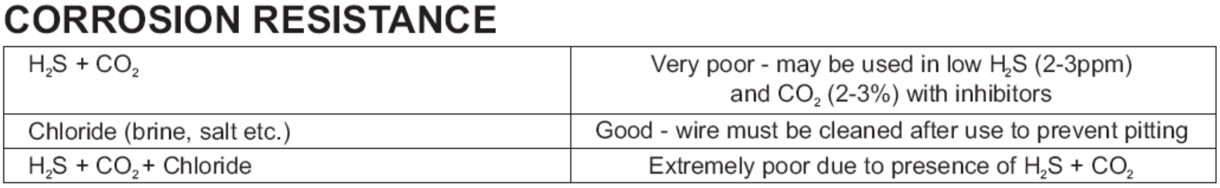


PHYSICAL PROPERTIES

Density	g/cm³	7.87	7.87	7.87
Coefficient of linear expansion	mm/m/°C	0.11	0.11	0.11
Wireline weight	lb/1000ft	22.66	31.23	41.84
Minimum wireline stretch	inch/100ft/100lb	0.70	0.51	0.38
Thermal conductivity	W/m.K	50	50	50
Specific heat	J/kg.K	532	532	532
Resistivity	µ Ohm. cm	17	17	17
Magnetic permeability		2420	2420	2420

2.2.5 Corrosion:

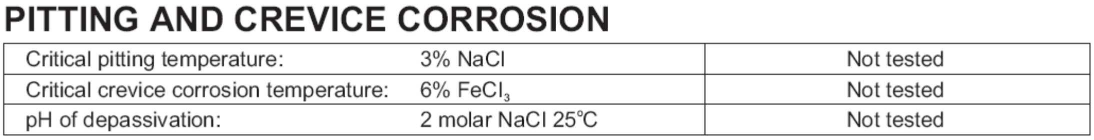
Table 2-9 : corrosion resistance



CORROSION RESISTANCE

$H_2S + CO_2$	Very poor - may be used in low H_2S (2-3ppm) and CO_2 (2-3%) with inhibitors
Chloride (brine, salt etc.)	Good - wire must be cleaned after use to prevent pitting
$H_2S + CO_2$ + Chloride	Extremely poor due to presence of $H_2S + CO_2$

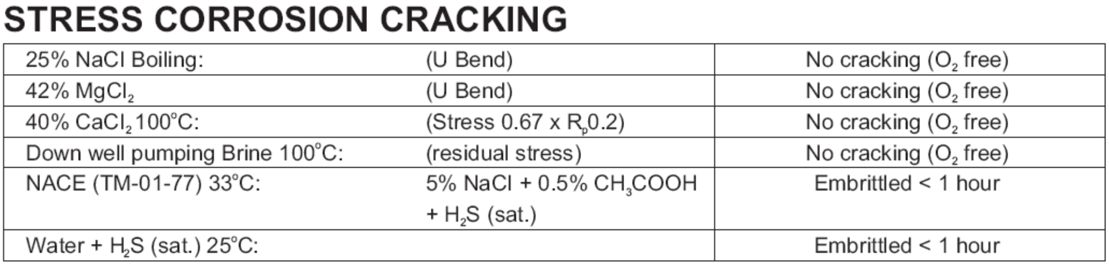
Table 2-10 : pitting and crevice corrosion



PITTING AND CREVICE CORROSION

Critical pitting temperature:	3% NaCl	Not tested
Critical crevice corrosion temperature:	6% $FeCl_3$	Not tested
pH of depassivation:	2 molar NaCl 25°C	Not tested

Table 2-11 :stress corrosion caracing



STRESS CORROSION CRACKING

25% NaCl Boiling:	(U Bend)	No cracking (O_2 free)
42% $MgCl_2$	(U Bend)	No cracking (O_2 free)
40% $CaCl_2$ 100°C:	(Stress 0.67 x R_p0.2)	No cracking (O_2 free)
Down well pumping Brine 100°C:	(residual stress)	No cracking (O_2 free)
NACE (TM-01-77) 33°C:	5% NaCl + 0.5% CH_3COOH + H_2S (sat.)	Embrittled < 1 hour
Water + H_2S (sat.) 25°C:		Embrittled < 1 hour

CHAPTER 3

Welding

3.1 Gas Tungsten Arc Welding (TIG) :

3.1.1 Development :

Main articles: forge welding, resistance welding, oxyfuel welding, and Gas tungsten arc welding

While examples of forge welding go back to the Bronze Age and the Iron Age, arc welding did not come into practice until much later. In 1802, Vasily Petrov discovered the electric arc, initiating the development of arc welding which continued with the inventions of metal electrodes by a Russian (Nikolay Slavyanov) and an American (C.L. Coffin) in the late 1800s even as carbon arc welding, which used a carbon electrode, gained popularity. Around 1900, A. P. Strohmenger released in Britain a coated metal electrode which gave a more stable arc. In 1919, alternating current welding was invented by C.J. Holslag but did not become popular for another decade.

Competing welding processes such as resistance welding and oxyfuel welding were developed during this time as well but both, especially the latter, faced stiff competition from arc welding especially after metal coverings (known as flux) for the electrode, to stabilize the arc and shield the base material from impurities, continued to be developed.

During World War I welding started to be used in shipbuilding in Great Britain in place of riveted steel plates. The Americans also became more accepting of the new technology when the process allowed them to repair their ships quickly after a German attack in the New York Harbor at the beginning of the war. Arc welding was first applied to aircraft during the war as well, and some German airplane fuselages were constructed using this process. In 1919, the British shipbuilder Cammell Laird started construction of merchant ship, the *Fullagar*, with an entirely welded hull she was launched in 1921.

During the 1920s, major advances were made in welding technology, including the 1920 introduction of automatic welding in which electrode wire was continuously fed. Shielding gas became a subject receiving much attention as scientists attempted to protect welds from the effects of oxygen and nitrogen in the atmosphere. Porosity and brittleness were the primary problems and the solutions that developed included the use of hydrogen, argon, and helium as welding atmospheres. During the following decade, further advances allowed for the welding of reactive metals such as aluminum and magnesium. This, in conjunction with developments in automatic welding, alternating current, and fluxes fed a major expansion of arc welding during the 1930s and then during World War II.

During the middle of the century, many new welding methods were invented. Submerged arc welding was invented in 1930 and continues to be popular today. Gas tungsten arc welding, after decades of development, was finally perfected in 1941 and gas metal arc welding followed in 1948, allowing for fast welding of non-ferrous materials but requiring expensive shielding gases. Using a consumable electrode and a carbon dioxide atmosphere as a shielding gas, it quickly became the most popular metal arc welding process. In 1957, the flux-cored arc welding process debuted in which the self-shielded wire electrode could be used with automatic equipment, resulting in greatly increased welding speeds. In that same year, plasma arc welding was invented. Electroslag welding was released in 1958 and was followed by its cousin, electrogas welding, in 1961.

3.1.2 Power supplies :

Figure 3-1 :A diesel powered welding generator (the electric generator is on the left) as used in Indonesia.

To supply the electrical energy necessary for arc welding processes, a number of different power supplies can be used. The most common classification is constant current power supplies and constant voltage power supplies. In arc welding, the voltage is directly related to the length of the arc, and the current is related to the amount of heat input. Constant current power supplies are most often used for manual welding processes such as gas tungsten arc welding and shielded metal arc welding, because they maintain a relatively constant current even as the voltage varies. This is important because in manual welding, it can be difficult to hold the electrode perfectly steady, and as a result, the arc length and thus voltage tend to fluctuate. Constant voltage power supplies hold the voltage constant and vary the current, and as a result, are most often used for automated welding processes such as gas metal arc welding, flux cored arc welding, and submerged arc welding. In these processes, arc length is kept constant, since any fluctuation in the distance between the wire and the base material is quickly rectified by a large change in current. For example, if the wire and the base material get too close, the current will rapidly increase, which in turn causes the heat to increase and the tip of the wire to melt, returning it to its original separation distance.

The direction of current used in arc welding also plays an important role in welding. Consumable electrode processes such as shielded metal arc welding and gas metal arc welding generally use direct current, but the electrode can be charged either positively or negatively. In welding, the positively charged anode will have a greater heat concentration and, as a result, changing the polarity of the electrode has an impact on weld properties. If the electrode is positively charged, it will melt more quickly, increasing weld penetration and welding speed. Alternatively, a negatively charged electrode results in more shallow welds. Non-consumable electrode processes, such as gas tungsten arc welding, can use either type of direct current (DC), as well as alternating current (AC). With direct current however, because the electrode only creates the arc and does not provide filler material, a positively charged electrode causes shallow welds, while a negatively charged electrode makes deeper welds. Alternating current rapidly moves between these two, resulting in medium-penetration welds. One disadvantage of AC, the fact that the arc must be re-ignited after every zero crossing, has been addressed with the invention of special power units that produce a square wave pattern instead of the normal sine wave, eliminating low-voltage time after the zero crossings and minimizing the effects of the problem.

3.1.3 Operation Modes :

GTAW can use a positive direct current, negative direct current or an alternating current, depending on the power supply set up. A negative direct current from the electrode causes a stream of electrons to collide with the surface, generating large amounts of heat at the weld region. This creates a deep, narrow weld. In the opposite process where the electrode is connected to the positive power supply terminal, positively charged ions flow from the tip of the electrode instead, so the heating action of the electrons is mostly on the electrode. This mode also helps to remove oxide layers from the surface of the region to be welded, which is good for metals such as Aluminium or Magnesium. A shallow, wide weld is produced from this mode, with minimum heat input. Alternating current gives a combination of negative and positive modes, giving a cleaning effect and imparts a lot of heat as well.

3.1.4 Safety :

Like other arc welding processes, GTAW can be dangerous if proper precautions are not taken. The process produces intense ultraviolet radiation, which can cause a form of sunburn and, in a few cases, trigger the development of skin cancer. Flying sparks and droplets of molten metal can cause severe burns and start a fire if flammable material is nearby, though GTAW generally produces very few sparks or metal droplets when performed properly.

It is essential that the welder wear suitable protective clothing, including leather gloves, a closed shirt collar to protect the neck (especially the throat), a protective long sleeve jacket and a suitable welding helmet to prevent retinal damage or ultraviolet burns to the cornea, often called arc eye. The shade of welding lens will depend upon the amperage of the welding current. Due to the absence of smoke in GTAW, the arc appears brighter than shielded metal arc welding and more ultraviolet radiation is produced. Exposure of bare skin near a GTAW arc for even a few seconds may cause a painful sunburn. Additionally, the tungsten electrode is heated to a white hot state like the filament of a lightbulb, adding greatly to the total radiated light and heat energy. Transparent welding curtains, made of a polyvinyl chloride plastic film, dyed in order to block UV radiation, are often used to shield nearby personnel from exposure.

Welders are also often exposed to dangerous gases and particulate matter. Shielding gases can displace oxygen and lead to asphyxiation, and while smoke is not produced, the arc in GTAW produces very short wavelength ultraviolet light, which causes surrounding air to break down and form ozone. Metals will volatilize and heavy metals can be taken into the lungs. Similarly, the heat can cause poisonous fumes to form from cleaning and degreasing materials. For example chlorinated products will break down producing poisonous phosgene. Cleaning operations using these agents should not be performed near the site of welding, and proper ventilation is necessary to protect the welder.

3.1.5 Applications :

While the aerospace industry is one of the primary users of gas tungsten arc welding, the process is used in a number of other areas. Many industries use GTAW for welding thin workpieces, especially nonferrous metals. It is used extensively in the manufacture of space vehicles, and is also frequently employed to weld small-diameter, thin-wall tubing such as those used in the bicycle industry. In addition, GTAW is often used to make root or first pass welds for piping of various sizes. In maintenance and repair work, the process is commonly used to repair tools and dies, especially components made of aluminum and magnesium.[11] Because the weld metal is not transferred directly across the electric arc like most open arc welding processes, a vast assortment of welding filler metal is available to the welding engineer. In fact, no other welding process permits the welding of so many alloys in so many product configurations. Filler metal alloys, such as elemental aluminum and chromium, can be lost through the electric arc from volatilization. This loss does not occur with the GTAW process. Because the resulting welds have the same chemical integrity as the original base metal or match the base metals more closely, GTAW welds are highly resistant to corrosion and cracking over long time periods, GTAW is the welding procedure of choice for critical welding operations like sealing spent nuclear fuel canisters before burial.

3.1.6 Quality :

Figure 3-2 : GTAW fillet weld

Engineers prefer GTAW welds because of its low-hydrogen properties and the match of mechanical and chemical properties with the base material. Maximum weld quality is assured by maintaining the cleanliness of the operation—all equipment and materials used must be free from oil, moisture, dirt and other impurities, as these cause weld porosity and consequently a decrease in weld strength and quality. To remove oil and grease, alcohol or similar commercial solvents may be used, while a stainless steel wire brush or chemical process can remove oxides from the surfaces of metals like aluminum. Rust on steels can be removed by first grit blasting the surface and then using a wire brush to remove any embedded grit. These steps are especially important when negative polarity direct current is used, because such a power supply provides no cleaning during the welding process, unlike positive polarity direct current or alternating current.

To maintain a clean weld pool during welding, the shielding gas flow should be sufficient and consistent so that the gas covers the weld and blocks impurities in the atmosphere. GTA welding in windy or drafty environments increases the amount of shielding gas necessary to protect the weld, increasing the cost and making the process unpopular outdoors.

Because of GTAW's relative difficulty and the importance of proper technique, skilled operators are employed for important applications. Welders should be qualified following the requirements of the American Welding Society or American Society of Mechanical Engineers. Low heat input, caused by low welding current or high welding speed, can limit penetration and cause the weld bead to lift away from the surface being welded. If there is too much heat input, however, the weld bead grows in width while the likelihood of excessive penetration and spatter increase. Additionally, if the welder holds the welding torch too far from the workpiece, shielding gas is wasted and the appearance of the weld worsens.

If the amount of current used exceeds the capability of the electrode, tungsten inclusions in the weld may result. Known as tungsten spitting, it can be identified with radiography and prevented by changing the type of electrode or increasing the electrode diameter. In addition, if the electrode is not well protected by the gas shield or the operator accidentally allows it to contact the molten metal, it can become dirty or contaminated. This often causes the welding arc to become unstable, requiring that electrode be ground with a diamond abrasive to remove the impurity.

3.1.7 **Equipment :**

Figure 3-3 : GTAW torch with various electrodes, cups, collets and gas diffusers

Figure 3-4 : GTAW torch, disassembled

The equipment required for the gas tungsten arc welding operation includes a welding torch utilizing a nonconsumable tungsten electrode, a constant-current welding power supply, and a shielding gas source.

3.1.8 **Welding torch :**

GTAW welding torches are designed for either automatic or manual operation and are equipped with cooling systems using air or water. The automatic and manual torches are similar in construction, but the manual torch has a handle while the automatic torch normally comes with a mounting rack. The angle between the centerline of the handle and the centerline of the tungsten electrode, known as the head angle, can be varied on some manual torches according to the preference of the operator. Air cooling systems are most often used for low-current operations (up to about 200 A), while water cooling is required for high-current welding (up to about 600 A). The torches are connected with cables to the power supply and with hoses to the shielding gas source and where used, the water supply.

The internal metal parts of a torch are made of hard alloys of copper or brass in order to transmit current and heat effectively. The tungsten electrode must be held firmly in the center of the torch with an appropriately sized collet, and ports around the electrode provide a constant flow of shielding gas. Collets are sized according to the diameter of the tungsten electrode they hold. The body of the torch is made of heat-resistant, insulating plastics covering the metal components, providing insulation from heat and electricity to protect the welder.

The size of the welding torch nozzle depends on the amount of shielded area desired. The size of the gas nozzle will depend upon the diameter of the electrode, the joint configuration, and the availability of access to the joint by the welder. The inside diameter of the nozzle is preferably at least three times the diameter of the electrode, but there are no hard rules. The welder will judge the effectiveness of the shielding and increase the nozzle size to increase the area protected by the external gas shield as needed. The nozzle must be heat resistant and thus is normally made of alumina or a ceramic material, but fused quartz, a glass-like substance, offers greater visibility. Devices can be inserted into the nozzle for special applications, such as gas lenses or valves to improve the control shielding gas flow to reduce turbulence and introduction of contaminated atmosphere into the shielded area. Hand switches to control welding current can be added to the manual GTAW torches.

3.1.9 Power supply :

Gas tungsten arc welding uses a constant current power source, meaning that the current (and thus the heat) remains relatively constant, even if the arc distance and voltage change. This is important because most applications of GTAW are manual or semiautomatic, requiring that an operator hold the torch. Maintaining a suitably steady arc distance is difficult if a constant voltage power source is used instead, since it can cause dramatic heat variations and make welding more difficult.

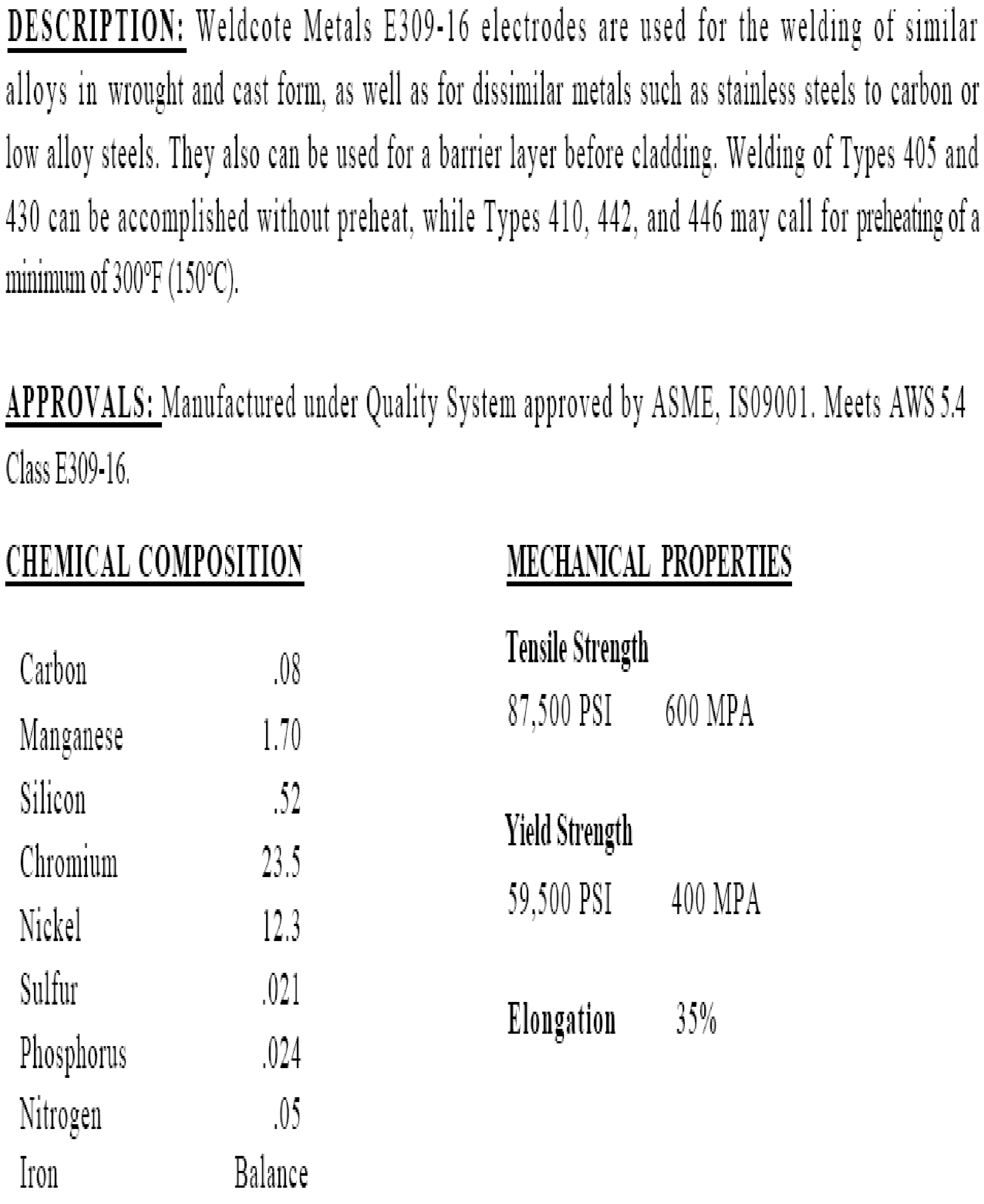
Figure 3-5 : GTAW power supply

The preferred polarity of the GTAW system depends largely on the type of metal being welded. Direct current with a negatively charged electrode (DCEN) is often employed when welding steels, nickel, titanium, and other metals. It can also be used in automatic GTA welding of aluminum or magnesium when helium is used as a shielding gas. The negatively charged electrode generates heat by emitting electrons which travel across the arc, causing thermal ionization of the shielding gas and increasing the temperature of the base material. The ionized shielding gas flows toward the electrode, not the base material. Direct current with a positively charged electrode (DCEP) is less common, and is used primarily for shallow welds since less heat is generated in the base material. Instead of flowing from the electrode to the base material, as in DCEN, electrons go the other direction, causing the electrode to reach very high temperatures. To help it maintain its shape and prevent softening, a larger electrode is often used. As the electrons flow toward the electrode, ionized shielding gas flows back toward the base material, cleaning the weld by removing oxides and other impurities and thereby improving its quality and appearance.

Alternating current, commonly used when welding aluminum and magnesium manually or semi-automatically, combines the two direct currents by making the electrode and base material alternate between positive and negative charge. This causes the electron flow to switch directions constantly, preventing the tungsten electrode from overheating while maintaining the heat in the base material. Surface oxides are still removed during the electrode-positive portion of the cycle and the base metal is heated more deeply during the electrode-negative portion of the cycle. Some power supplies enable operators to use an unbalanced alternating current wave by modifying the exact percentage of time that the current spends in each state of polarity, giving them more control over the amount of heat and cleaning action supplied by the power source. In addition, operators must be wary of rectification, in which the arc fails to reignite as it passes from straight polarity (negative electrode) to reverse polarity (positive electrode). To remedy the problem, a square wave power supply can be used, as can high-frequency voltage to encourage ignition.

3.1.10 Electrode e309 and e316 :

We have used tow kind of electrode e309 and e 316



DESCRIPTION: Weldcote Metals E309-16 electrodes are used for the welding of similar alloys in wrought and cast form, as well as for dissimilar metals such as stainless steels to carbon or low alloy steels. They also can be used for a barrier layer before cladding. Welding of Types 405 and 430 can be accomplished without preheat, while Types 410, 442, and 446 may call for preheating of a minimum of 300°F (150°C).

APPROVALS: Manufactured under Quality System approved by ASME, IS09001. Meets AWS 5.4 Class E309-16.

CHEMICAL COMPOSITION

Carbon	.08
Manganese	1.70
Silicon	.52
Chromium	23.5
Nickel	12.3
Sulfur	.021
Phosphorus	.024
Nitrogen	.05
Iron	Balance

MECHANICAL PROPERTIES

Tensile Strength

87,500 PSI 600 MPA

Yield Strength

59,500 PSI 400 MPA

Elongation 35%

3.1.11 Electrode :

ISO Class	ISO Color	AWS Class	AWS Color	Alloy
WP	Green	EWP	Green	None
WC20	Gray	EWCe-2	Orange	~2% CeO_2
WL10	Black	EWLa-1	Black	~1% La_2O_3
WL15	Gold	EWLa-1.5	Gold	~1.5% La_2O_3
WL20	Sky-blue	EWLa-2	Blue	~2% La_2O_3
WT10	Yellow	EWTh-1	Yellow	~1% ThO_2
WT20	Red	EWTh-2	Red	~2% ThO_2
WT30	Violet			~3% ThO_2
WT40	Orange			~4% ThO_2
WY20	Blue			~2% Y_2O_3
WZ3	Brown	EWZr-1	Brown	~0.3% ZrO_2
WZ8	White			~0.8% ZrO_2

The electrode used in GTAW is made of tungsten or a tungsten alloy, because tungsten has the highest melting temperature among pure metals, at 3,422 °C (6,192 °F). As a result, the electrode is not consumed during welding, though some erosion (called burn-off) can occur. Electrodes can have either a clean finish or a ground finish—clean finish electrodes have been chemically cleaned, while ground finish electrodes have been ground to a uniform size and have a polished surface, making them optimal for heat conduction. The diameter of the electrode can vary between 0.5 millimeter and 6.4 millimeters (0.02–

0.25 in), and their length can range from 75 to 610 millimeters (3–24 in).

A number of tungsten alloys have been standardized by the International Organization for Standardization and the American Welding Society in ISO 6848 and AWS A5.12, respectively, for use in GTAW electrodes, and are summarized in the adjacent table. Pure tungsten electrodes (classified as WP or EWP) are general purpose and low cost electrodes. Cerium oxide (or ceria) as an alloying element improves arc stability and ease of starting while decreasing burn-off. Using an alloy of lanthanum oxide (or lanthana) has a similar effect. Thorium oxide (or thoria) alloy electrodes were designed for DC applications and can withstand somewhat higher temperatures while providing many of the benefits of other alloys. However, it is somewhat radioactive. Inhalation of the thorium grinding dust during preparation of the electrode is hazardous to one's health. As a replacement to thoriated electrodes, electrodes with larger concentrations of lanthanum oxide can be used. Electrodes containing zirconium oxide (or zirconia) increase the current capacity while improving arc stability and starting and increasing electrode life. In addition, electrode manufacturers may create alternative tungsten alloys with specified metal additions, and these are designated with the classification EWG under the AWS system.

Filler metals are also used in nearly all applications of GTAW, the major exception being the welding of thin materials. Filler metals are available with different diameters and are made of a variety of materials. In most cases, the filler metal in the form of a rod is added to the weld pool manually, but some applications call for an automatically fed filler metal, which often is stored on spools or coils.[19]

3.1.12 Shielding gas :

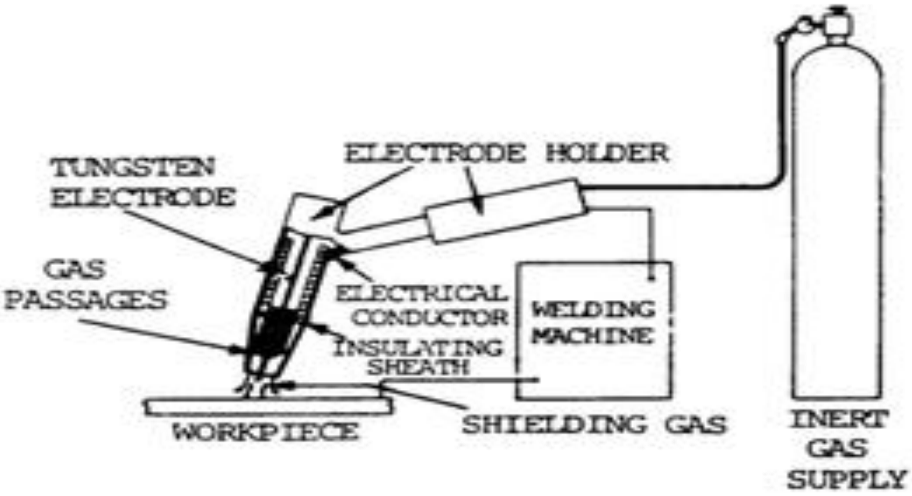


Figure 3-6 : GTAW system setup

As with other welding processes such as gas metal arc welding, shielding gases are necessary in GTAW to protect the welding area from atmospheric gases such as nitrogen and oxygen, which can cause fusion defects, porosity, and weld metal embrittlement if they come in contact with the electrode, the arc, or the welding metal. The gas also transfers heat from the tungsten electrode to the metal, and it helps start and maintain a stable arc.

The selection of a shielding gas depends on several factors, including the type of material being welded, joint design, and desired final weld appearance. Argon is the most commonly used shielding gas for GTAW, since it helps prevent defects due to a varying arc length. When used with alternating current, the use of argon results in high weld quality and good appearance. Another common shielding gas, helium, is most often used to increase the weld penetration in a joint, to increase the welding speed, and to weld metals with high heat conductivity, such as copper and aluminum. A significant disadvantage is the difficulty of striking an arc with helium gas, and the decreased weld quality associated with a varying arc length.

Argon-helium mixtures are also frequently utilized in GTAW, since they can increase control of the heat input while maintaining the benefits of using argon. Normally, the mixtures are made with primarily helium (often about 75% or higher) and a balance of argon. These mixtures increase the speed and quality of the AC welding of aluminum, and also make it easier to strike an arc. Another shielding gas mixture, argon-hydrogen, is used in the mechanized welding of light gauge stainless steel, but because hydrogen can cause porosity, its uses are limited.[20] Similarly, nitrogen can sometimes be added to argon to help stabilize the austenite in austentitic stainless steels and increase penetration when welding copper. Due to porosity problems in ferritic steels and limited benefits, however, it is not a popular shielding gas additive.[21]

3.1.13 Materials :

Gas tungsten arc welding is most commonly used to weld stainless steel and nonferrous materials, such as aluminum and magnesium, but it can be applied to nearly all metals, with notable exceptions being lead and zinc. Its applications involving carbon steels are limited not because of process restrictions, but because of the existence of more economical steel welding techniques, such as gas metal arc welding and shielded metal arc welding. Furthermore, GTAW can be performed in a variety of other-than-flat positions, depending on the skill of the welder and the materials being welded.

3.1.14 Non-consumable electrode methods :

Gas tungsten arc welding (GTAW), or tungsten inert gas (TIG) welding, is a manual welding process that uses a non-consumable electrode made of tungsten, an inert or semi-inert gas mixture, and a separate filler material. Especially useful for welding thin materials, this method is characterized by a stable arc and high quality welds, but it requires significant operator skill and can only be accomplished at relatively low speeds. It can be used on nearly all weldable metals, though it is most often applied to stainless steel and light metals. It is often used when quality welds are extremely important, such as in bicycle, aircraft and naval applications.[21] A related process, plasma arc welding, also uses a tungsten electrode but uses plasma gas to make the arc. The arc is more concentrated than the GTAW arc, making transverse control more critical and thus generally restricting the technique to a mechanized process. Because of its stable current, the method can be used on a wider range of material thicknesses than can the GTAW process and is much faster. It can be applied to all of the same materials as GTAW except magnesium; automated welding of stainless steel is one important application of the process. A variation of the process is plasma cutting, an efficient steel cutting process.

Other arc welding processes include atomic hydrogen welding, carbon arc welding, electroslag welding, electrogas welding, and stud arc welding.

3.1.15 Corrosion issues :

Main articles: Hydrogen embrittlement and Galvanic corrosion

Some materials, notably high-strength steels, aluminium, and titanium alloys, are susceptible to hydrogen embrittlement. If the electrodes used for welding contain traces of moisture, the water decomposes in the heat of the arc and the liberated hydrogen enters the lattice of the material, causing its brittleness. Electrodes for such materials, with special low-hydrogen coating, are delivered in sealed moisture-proof packagings. New electrodes can be used straight from the can, but when moisture absorption may be suspected, they have to be dried by baking (usually at 800 to 1000 °F (425 to 550 °C)) in a drying oven. Flux used has to be kept dry as well.

Some austenitic stainless steels and nickel-based alloys are prone to intergranular corrosion. When subjected to temperatures around 700 °C (1,300 °F) for too long time, chromium reacts with carbon in the material, forming chromium carbide and depleting the crystal edges of chromium, impairing their corrosion resistance in a process called sensitization. Such sensitized steel undergoes corrosion in the areas near the welds where the temperature-time was favorable for forming the carbide. This kind of corrosion is often termed weld decay.

Knifeline attack (KLA) is another kind of corrosion affecting welds, impacting steels stabilized by niobium. Niobium and niobium carbide dissolves in steel at very high temperatures. At some cooling regimes, niobium carbide does not precipitate, and the steel then behaves like unstabilized steel, forming chromium carbide instead. This affects only a thin zone several millimeters wide in the very vicinity of the weld, making it difficult to spot and increasing the corrosion speed. Structures made of such steels have to be heated in a whole to about 1,950 °F (1,070 °C), when the chromium carbide dissolves and niobium carbide forms. The cooling rate after this treatment is not important.

Filler metal (electrode material) improperly chosen for the environmental conditions can make them corrosion-sensitive as well. There are also issues of galvanic corrosion if the electrode composition is sufficiently dissimilar to the materials welded, or the materials are dissimilar themselves. Even between different grades of nickel-based stainless steels, corrosion of welded joints can be severe, despite that they rarely undergo galvanic corrosion when mechanically joined.

3.1.16 Heat and sparks :

Because many common welding procedures involve an open electric arc or flame, the risk of burns is significant. To prevent them, welders wear protective clothing in the form of heavy leather gloves and protective long sleeve jackets to avoid exposure to extreme heat, flames, and sparks.

3.1.17 Eye damage :

The brightness of the weld area leads to a condition called arc eye in which ultraviolet light causes inflammation of the cornea and can burn the retinas of the eyes. Goggles and helmets with dark face plates are worn to prevent this exposure and, in recent years, new helmet models have been produced featuring a face plate that self-darkens upon exposure to high amounts of UV light. To protect bystanders, transparent welding curtains often surround the welding area. These curtains, made of a polyvinyl chloride plastic film, shield nearby workers from exposure to the UV light from the electric arc, but should not be used to replace the filter glass used in helmets.

Those dark face plates must be much darker than those in sunglasses or blowtorching goggles. Sunglasses and blowtorching goggles are ***not*** adequate for arc welding protection.

In 1970, a Swedish doctor, Åke Sandén, developed a new type of welding goggles that used a multilayer interference filter to block most of the light from the arc. He had observed that most welders could not see well enough, with the mask on, to strike the arc, so they would flip the mask up, then flip it down again once the arc was going: this exposed their naked eyes to the intense light for a while. By coincidence, the spectrum of an electric arc has a notch in it, which coincides with the yellow sodium line. Thus, a welding shop could be lit by sodium vapor lamps or daylight, and the welder could see well to strike the arc. The Swedish government required these masks to be used for arc welding, but they were not used in the United States. They may have disappeared.

3.1.19 Inhaled matter :

Welders are also often exposed to dangerous gases and particulate matter. Processes like flux-cored arc welding and shielded metal arc welding produce smoke containing particles of various types of oxides. The size of the particles in question tends to influence the toxicity of the fumes, with smaller particles presenting a greater danger. Additionally, many processes produce various gases (most commonly carbon dioxide and ozone, but others as well) that can prove dangerous if ventilation is inadequate. Furthermore, the use of compressed gases and flames in many welding processes pose an explosion and fire risk; some common precautions include limiting the amount of oxygen in the air and keeping combustible materials away from the workplace.

3.2 Arc welding :

3.2.1 Development :

After the discovery of the electric arc in 1800 by Humphry Davy, arc welding developed slowly. C. L. Coffin had the idea of welding in an inert gas atmosphere in 1890, but even in the early 1900s, welding non-ferrous materials like aluminum and magnesium remained difficult, because these metals reacted rapidly with the air, resulting in porous and dross-filled welds. Processes using flux covered electrodes did not satisfactorily protect the weld area from contamination. To solve the problem, bottled inert gases were used in the beginning of the 1930s. A few years later, a direct current, gas-shielded welding process emerged in the aircraft industry for welding magnesium.

This process was perfected in 1941, and became known as heliarc or tungsten inert gas welding, because it utilized a tungsten electrode and helium as a shielding gas. Initially, the electrode overheated quickly, and in spite of tungsten's high melting temperature, particles of tungsten were transferred to the weld. To address this problem, the polarity of the electrode was changed from positive to negative, but this made it unsuitable for welding many non-ferrous materials. Finally, the development of alternating current units made it possible to stabilize the arc and produce high quality aluminum and magnesium welds.

Developments continued during the following decades. Linde Air Products developed water-cooled torches that helped to prevent overheating when welding with high currents. Additionally, during the 1950s, as the process continued to gain popularity, some users turned to carbon dioxide as an alternative to the more expensive welding atmospheres consisting of argon and helium. However, this proved unacceptable for welding aluminum and magnesium because it reduced weld quality, and as a result, it is rarely used with GTAW today.

3.2.2 **Operation :**

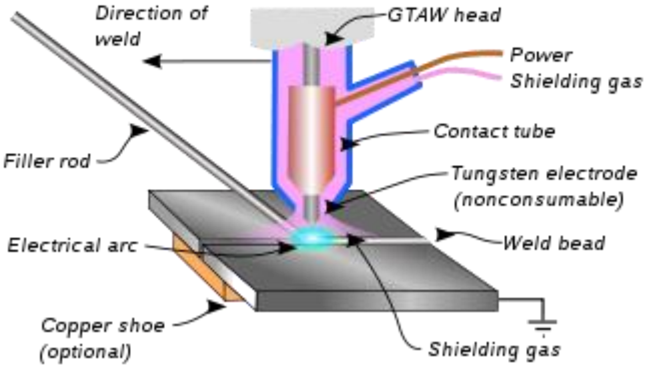


Figure 3-7 : GTAW weld area

Manual gas tungsten arc welding is often considered the most difficult of all the welding processes commonly used in industry. Because the welder must maintain a short arc length, great care and skill are required to prevent contact between the electrode and the workpiece. Unlike most other welding processes, GTAW normally requires two hands, since most applications require that the welder manually feed a filler metal into the weld area with one hand while manipulating the welding torch in the other. However, some welds combining thin materials (known as autogenous or fusion welds) can be accomplished without filler metal; most notably edge, corner, and butt joints.

To strike the welding arc, a high frequency generator provides a path for the welding current through the shielding gas, allowing the arc to be struck when the separation between the electrode and the workpiece is approximately 1.5–3 mm (0.06–0.12 in). Bringing the two into contact in a "touch start" ("scratch start") also serves to strike an arc. This technique can cause contamination of the weld and electrode. Once the arc is struck, the welder moves the torch in a small circle to create a welding pool, the size of which depends on the size of the electrode and the amount of current. While maintaining a constant separation between the electrode and the workpiece, the operator then moves the torch back slightly and tilts it backward about 10–15 degrees from vertical. Filler metal is added manually to the front end of the weld pool as it is needed.

Welders often develop a technique of rapidly alternating between moving the torch forward (to advance the weld pool) and adding filler metal. The filler rod is withdrawn from the weld pool each time the electrode advances, but it is never removed from the gas shield to prevent oxidation of its surface and contamination of the weld. Filler rods composed of metals with low melting temperature, such as aluminum, require that the operator maintain some distance from the arc while staying inside the gas shield. If held too close to the arc, the filler rod can melt before it makes contact with the weld puddle. As the weld nears completion, the arc current is often gradually reduced to allow the weld crater to solidify and prevent the formation of crater cracks at the end of the weld.

3.2.3 Process variations :

3.2.3.1 Pulsed-current :

In the pulsed-current mode, the welding current rapidly alternates between two levels. The higher current state is known as the pulse current, while the lower current level is called the background current. During the period of pulse current, the weld area is heated and fusion occurs. Upon dropping to the background current, the weld area is allowed to cool and solidify. Pulsed-current GTAW has a number of advantages, including lower heat input and consequently a reduction in distortion and warpage in thin workpieces. In addition, it allows for greater control of the weld pool, and can increase weld penetration, welding speed, and quality. A similar method, manual programmed GTAW, allows the operator to program a specific rate and magnitude of current variations, making it useful for specialized applications.

3.2.3.2 Dabber :

The dabber variation is used to precisely place weld metal on thin edges. The automatic process replicates the motions of manual welding by feeding a cold filler wire into the weld area and dabbing (or oscillating) it into the welding arc. It can be used in conjunction with pulsed current, and is used to weld a variety of alloys, including titanium, nickel, and tool steels. Common applications include rebuilding seals in jet engines and building up saw blades, milling cutters, drill bits, and mower blades.

3.2.4 Hot Wire :

Welding filler metal can be resistance heated to a temperature near its melting point before being introduced into the weld pool. This increases the deposition rate of machine and automatic GTAW welding processes. More pounds per hour of filler metal is introduced into the weld joint than when filler metal is added cold and the heat of the electric arc introduces all of the heat. This process is used extensively in base material build up before machining, clad metal overlays, and hardfacing operations.

3.3 Dissimilar welding:

3.3.1 General scope:

Welding dissimilar metals often introduces new difficulties to welding because most materials do not easily fuse to form a strong bond. However welds are dissimilar materials have numerous applications in manufacturing, repair work and prevention of corrosion and oxidation. In some joints, a compatible filler metal is chosen to help form the bond, and this filler metal can be the same as one of the base materials. For example, using a stainless steel filler metal stainless steel and carbon steel as base materials. On the other hand, a different metal such as a nickel filler metal can be used for joining steel and cast iron. Very different materials may be coated or buttered with a material compatible with a particular filler metal, and then welded.

When welding dissimilar metals, the joint must have an accurate fit, with proper gab dimensions and bevel angles. Care should be taken to avoid melting excessive base material. Pulse current is particularly useful for these applications, as it helps limit the heat input. The filler metal should be added quickly, and a large weld pool should be avoided to prevent dilutions of the base materials.

3.3.2 Important of dissimilar welding :

With increase damage in the application requirements, dissimilar material joining becomes inevitable in engineering industries. There are many issues/problems associated with the joining of dissimilar materials, depending on the materials being joined and the process employed. A few of general problems that are encountered during welding and the resultant weldments are: (a)carbon migration from the higher carbon containing alloy to relatively lower carbon alloy steel, especially those which are highly alloyed, (b)the differences in thermal expansion coefficients, resulting in differences in thermal residual stresses across the different regions of weldment, (c)difficulty in executing the post weld heat treatment, especially in combination where in either of materials being joined is susceptible to undesirable precipitation at elevated temperatures, (d) electrochemical property variation, in the weldment, resulting in environmentally assisted problems. Joining of plan carbon steel to ausenitic stainless steel has widely been attempted for applications in thermal power industries the importance of selection of welding consumable, especially the nickel bearing alloys, for dissimilar weld joints in nuclear application has also been reported in the literature.

With dissimilar weld joints becoming increasingly important in different application areas, attention is now paid for the understanding of the structure-property relationship in joints between ferrite steels and duplex stainless steel (DSS); however, the information on this subject is limited. In recent times, there were also a few attempts to accomplish surfacing/overlaying of DSS to CS by submerged are surfacing technique and explosive bonding for corrosion resistance applications. Shielded metal arc welding (SMAW) is the most widely employed joining process in engineering industries, especially in those dealing with structural and piping application. In the current work , an attempt has been made to produce dissimilar welds between a DSS and a plain CS, employing the SMAW process using two different welding consumable. The resultant weldments were characterized for their microstructure, mechanical properties and corrosion behavior.

3.3.3 Applications of dissimilar welding :

In power generation industry, various components/systems operate at different service condition and hence appropriate materials are used for these components/systems. Component operating at high temperature are mad of stainless steel and those operating on lower temperature are made of ferritic steel. Therefore, dissimilar joints are inevitable in linking the components/systems made of different materials. The dissimilar metal joints are prone to frequent failures and the causes can be one of the following : (a) difference in mechanical properties across the weld joints and the coefficients of thermal expansion (CTE) of the two typed of steel. (b) general alloying problems of two different base metals such as brittle phase formation and dilution. (c) carbon migration from the ferritic steel into the stainless steel. (d) preferential oxidation at the interface. (e) residual stresses present in the weld joints . (f)service conditions and other factors .

Operation experience with dissimilar weld joints has also shown that a significant number of failure occurred in less than expected service life. A majority of transition joint failures in austenitic/ferritic steel joints occur in the heat affected zone (HAZ) of ferritic steel. In the power plants, there there is strong evidence that residual stress is a major cause of cracking in welds and HAZ regions during service. A dilution layer is also presentin the weld metal adjacent to fusion line due to carbon migration from ferritic steel to the weld metal. From the failure analysis, it was concluded that the cyclic stresses produced in the HAZ of ferritic steel during the high temperature service, because of the difference in the coefficient of thermal expansion of ferritic steel and weld metal would have produced the cracking along/adjacent to the fusion line and also in the HAZ of the ferritic steel. It was also concluded that the residual stresses present in the weld joint. These joints involve the use of intermediate onconel-82 buttering on ferritic steel and stress relief heat treatment (SRHT) at 998 k (725C) prior to the fill upof the weld joint. The objective of this study is to find out the residual stress profile across dissimilar pipe weld joints made between 2.24Cr -1Mo ferritic steel and AISI type 316 stainless steel with and without incinel-82 buttering, using the non-distructive X-ray deffectration (XRD) technequeand to assess the effectiveness of the buttering on the extent of reduction in the residual stresses.

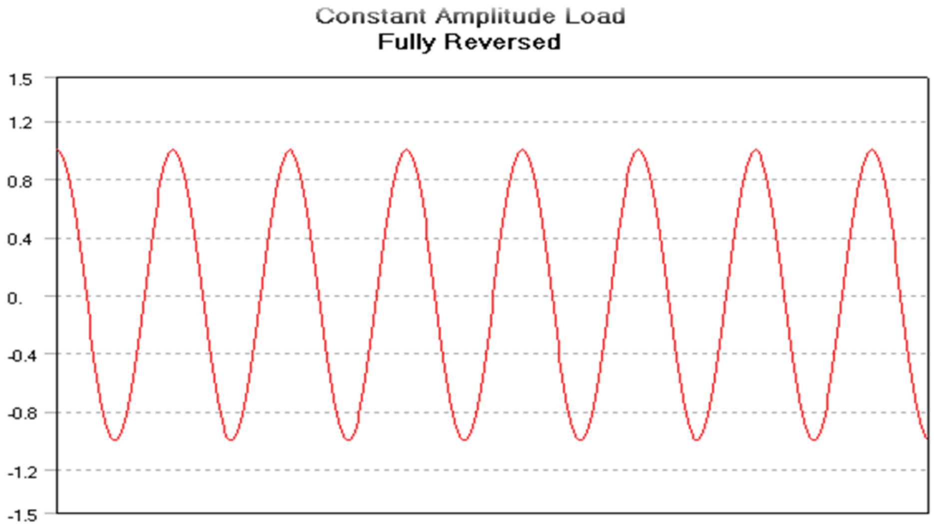
4.2.1 Materials :

A large part of a fatigue analysis is getting an accurate description of the fatigue material properties . Since fatigue is so empirical , sample fatigue curves are include only for structural steel and aluminum materials. These properties are included as a guide only with intent for the user to provide his/her own fatigue data for more accurate analysis . In the case of assemblies with different materials , each part will use its own fatigue material properties just as it uses its own static properties (like modulus of elasticity) .

4.2.1 Analysis :

To create fatigue results , a fatigue tool must first be inserted into the tree. This can be done through the solution toolbar or through context menus .The details view of the fatigue tool is used to defined the various aspects of a fatigue analysis such as loading type , handling of mean stress effects and more . As seen in Figure 1 , a graphical representation of the loading and mean stress effects is displayed when a fatigue tool is selected by the user . This can be very useful to help a novice understand the fatigue loading and possible effects of a mean stress .

FIG 1 fatigue tool information page in analysis



4.4.1 Loading :

Fatigue , by definition , is caused by changing the load on a component over time . Thus , unlike the static stress safety tools, which perform calculations for a single stress, fatigue damage occurs when the stress at a point changes over time . ANALYSIS can perform fatigue calculation for either constant amplitude loading or properties non-constant amplitude loading . A scale factor can be applied to the base loading if desired . This option, located under the "loading" section in the details view , is useful to see the effect of different finite element load magnitudes without having to re-run the stress analysis .

. constant amplitude, proportional loading :

This is the Classic ,"back of the envelope " calculation .Loading is of constant amplitude because only 1 set of finite element stress result along with a loading ratio is required to calculate the alternating and mean stress. The loading ratio is defined as the ratio of the second load to the first load (LR=L2/L1). Loading is proportional since only 1 set of finite element stress result is needed (principal stress axes do not change over time) .No cumulative damage calculation need to be done. Common types of constant amplitude loading are full reversed (apply a load then apply an equal and opposite load ; a load ratio of -1) and zero – based (apply a load then remove it ; a load ratio of 0) . Full reversed, zero-based , or a specified loading ratio can be defined in the details view under the " loading " section.

Non-constant amplitude, proportional loading:

In this case ,again only 1 set of results are needed, however instead of using a single load ratio to calculate the alternating and mean stress, the load ratio varies over time. Think of this as coupling an FEM analysis with strain-gauge results collected over a given time interval. Cumulative damage calculations including cycle counting and damage summation need to be done. A rainflow cycle counting method is used to identify stress reversals and miner's rule is used to perform the damage summation.

Chapter 5

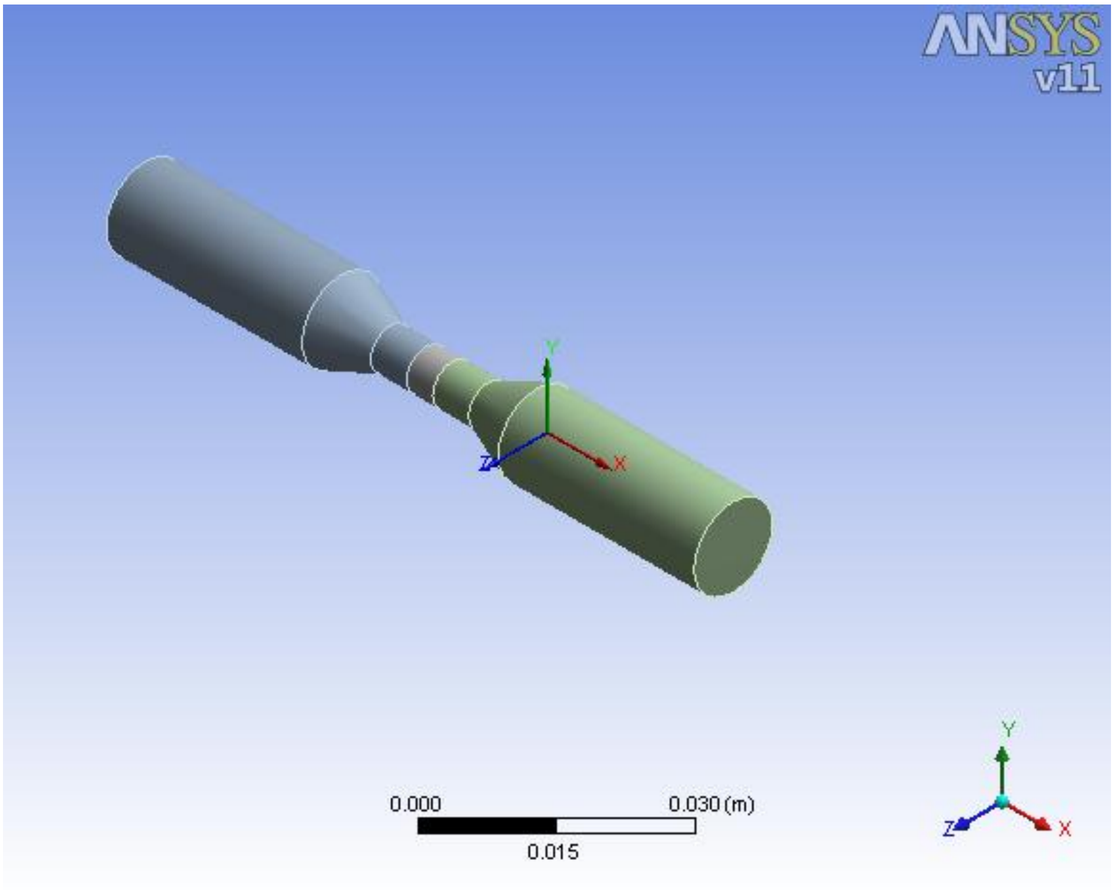
5-1 results:

Fatigue test on model by using:

-inventor (to draw the elements and assemble)

-analysis(to apply the forces on the model and simulation the stress and fatigue test on it)

After make all that ,the results are:



5.2 apply 2500N:

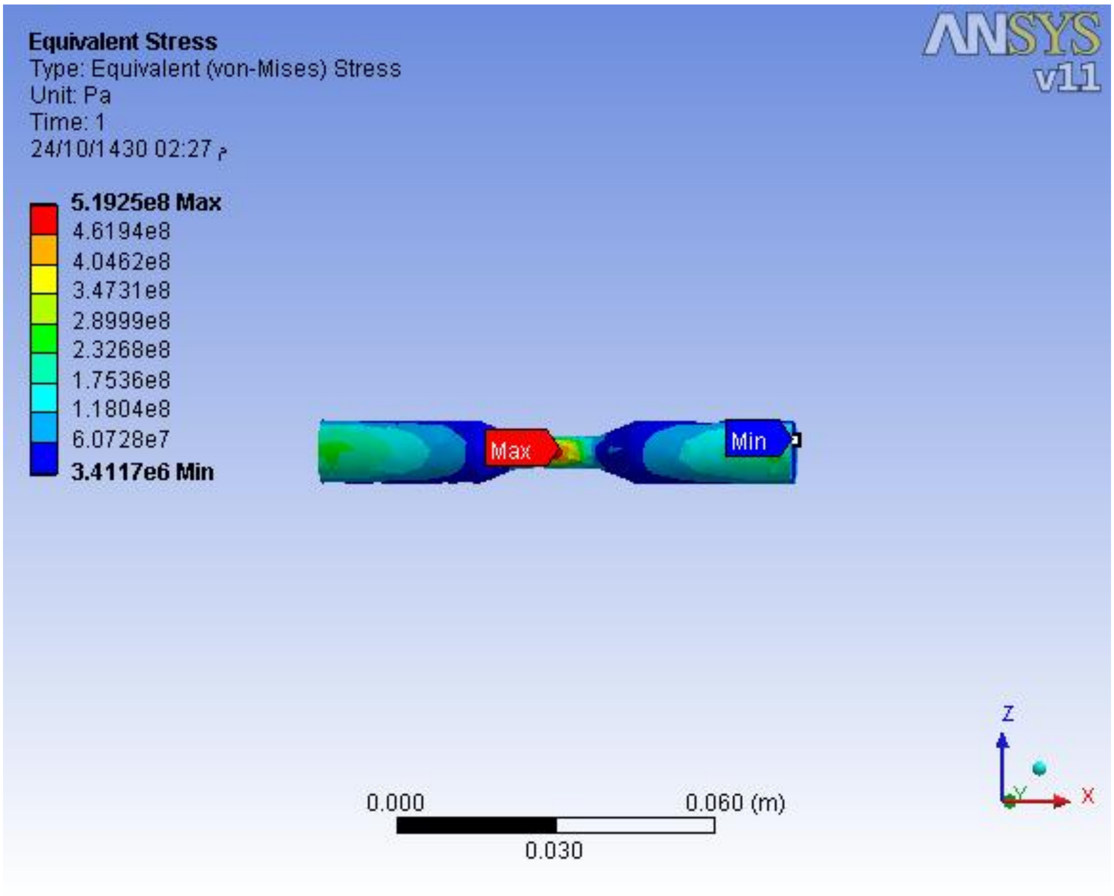


Fig.5.2.1.equivalent stess

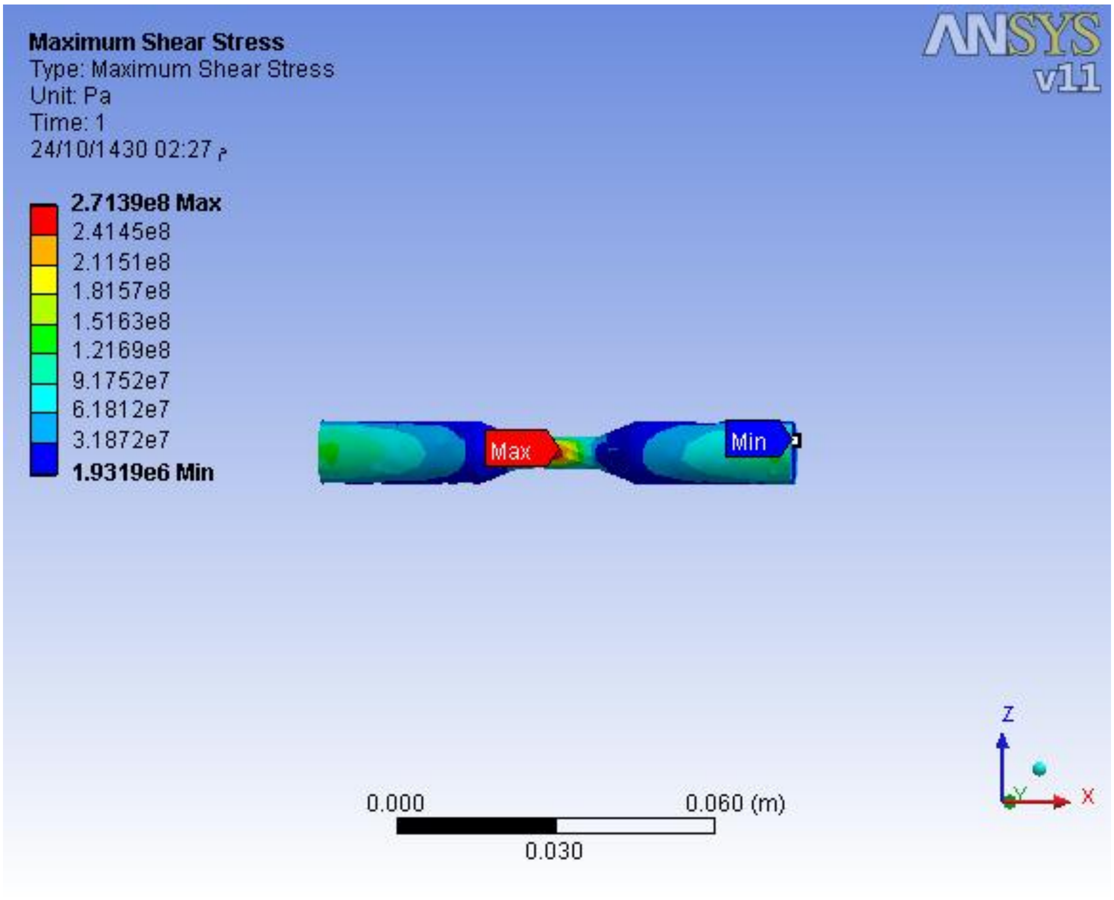


fig.5.2.2.maximum shear stess

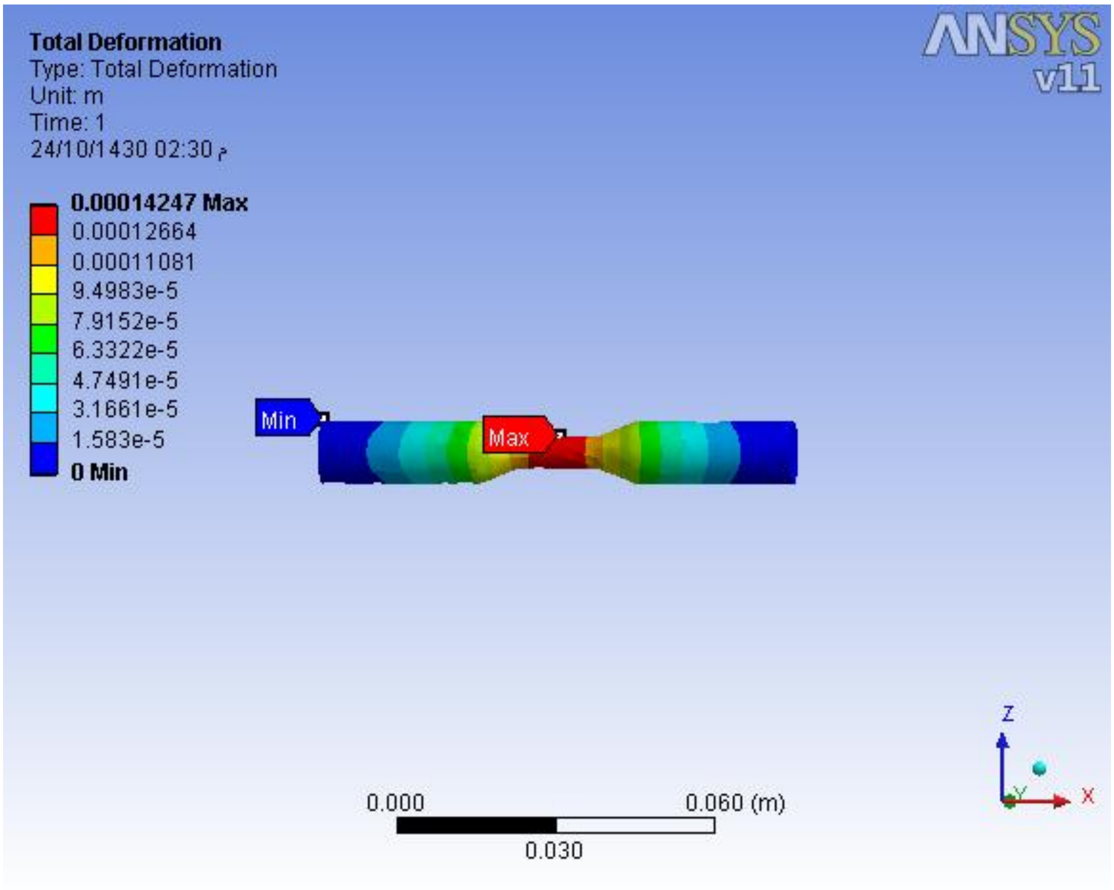


fig.5.2.3.total deformation

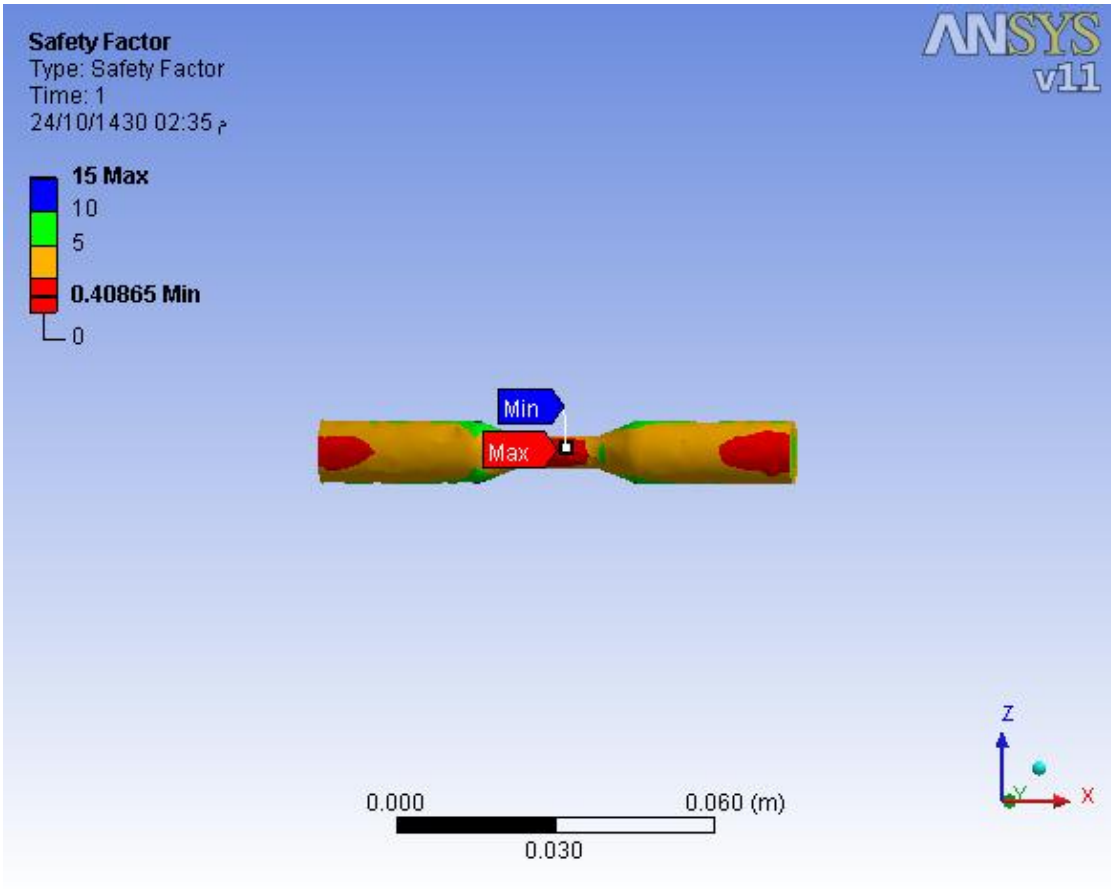


fig.5.2.4.safety factor

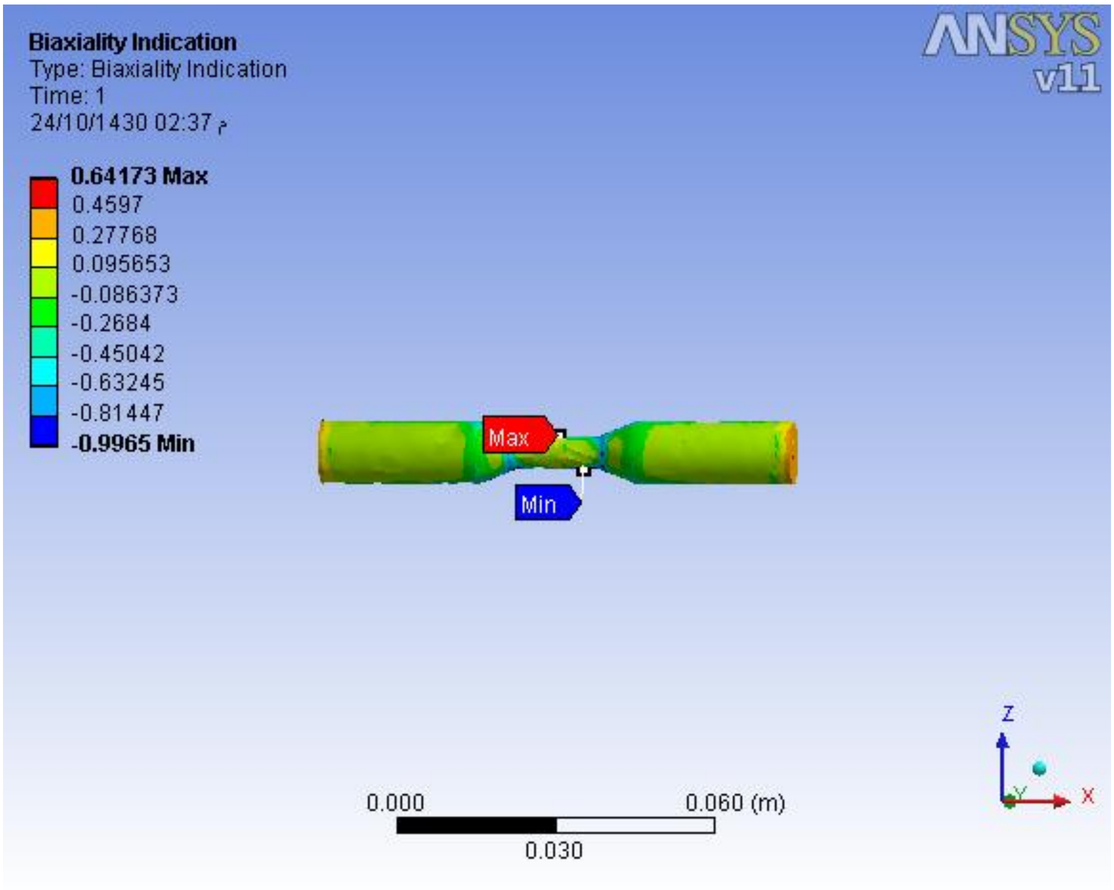


fig.5.2.5.biaxiality indication

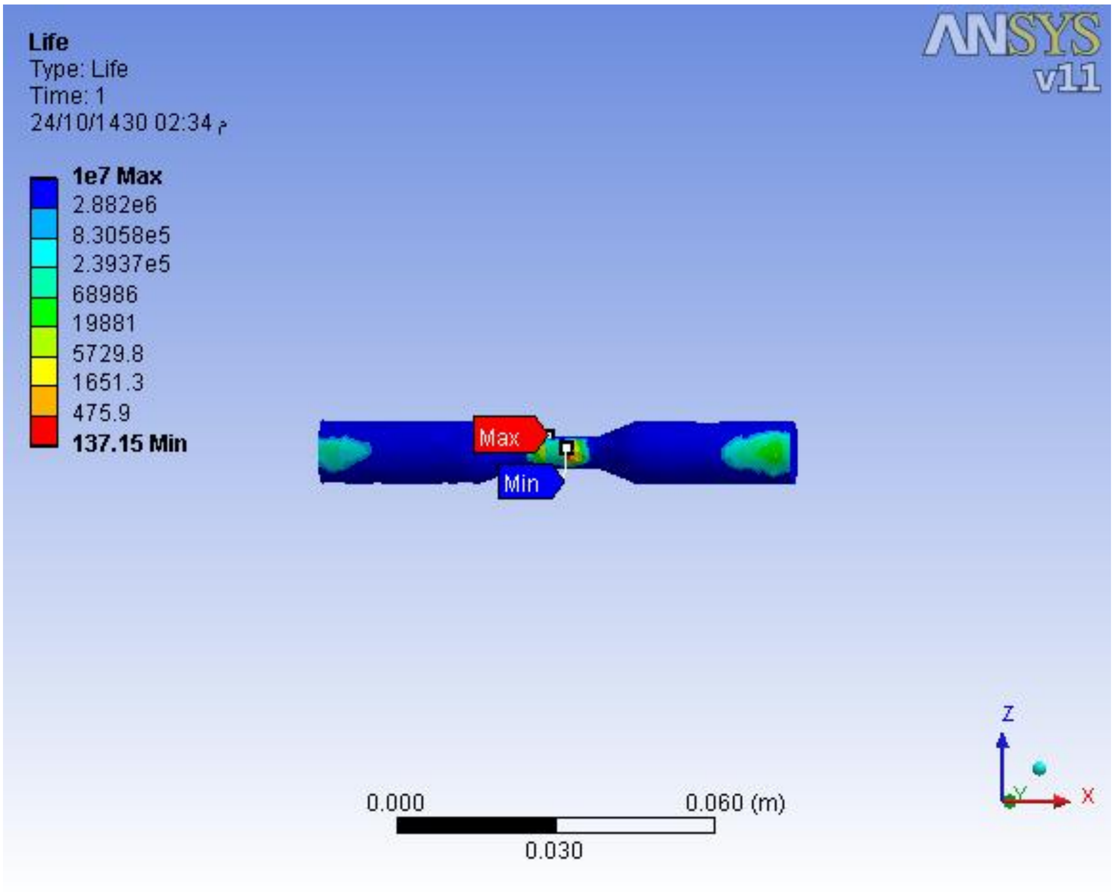


fig 5.2.6.fatigue life

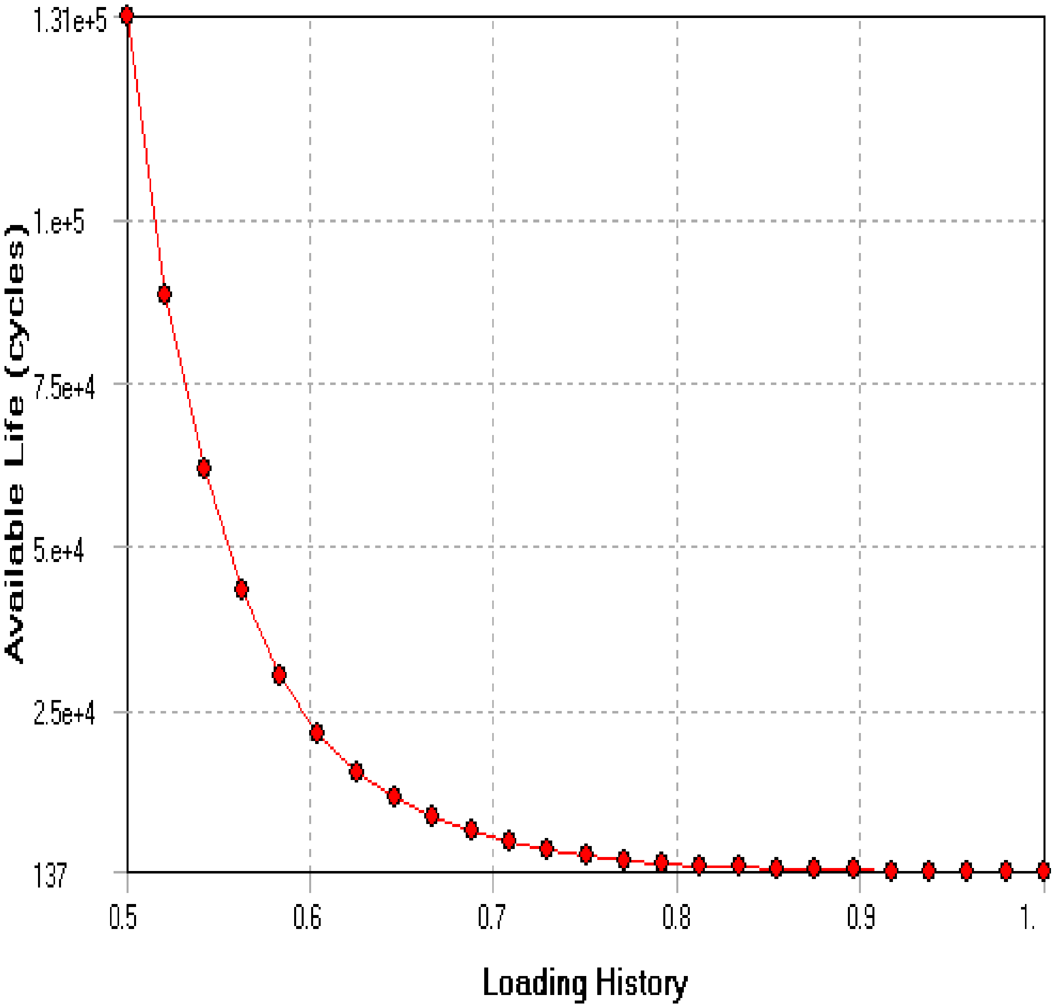


Fig.5.2.7.relitionshap between cycles and loading history

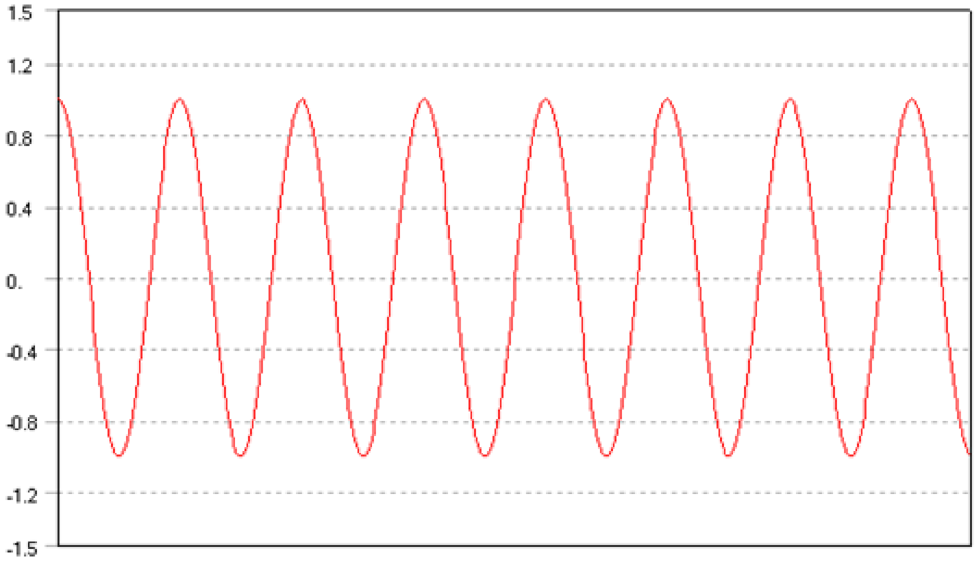


Fig.5.2.8.constant amplitude load fully reversed

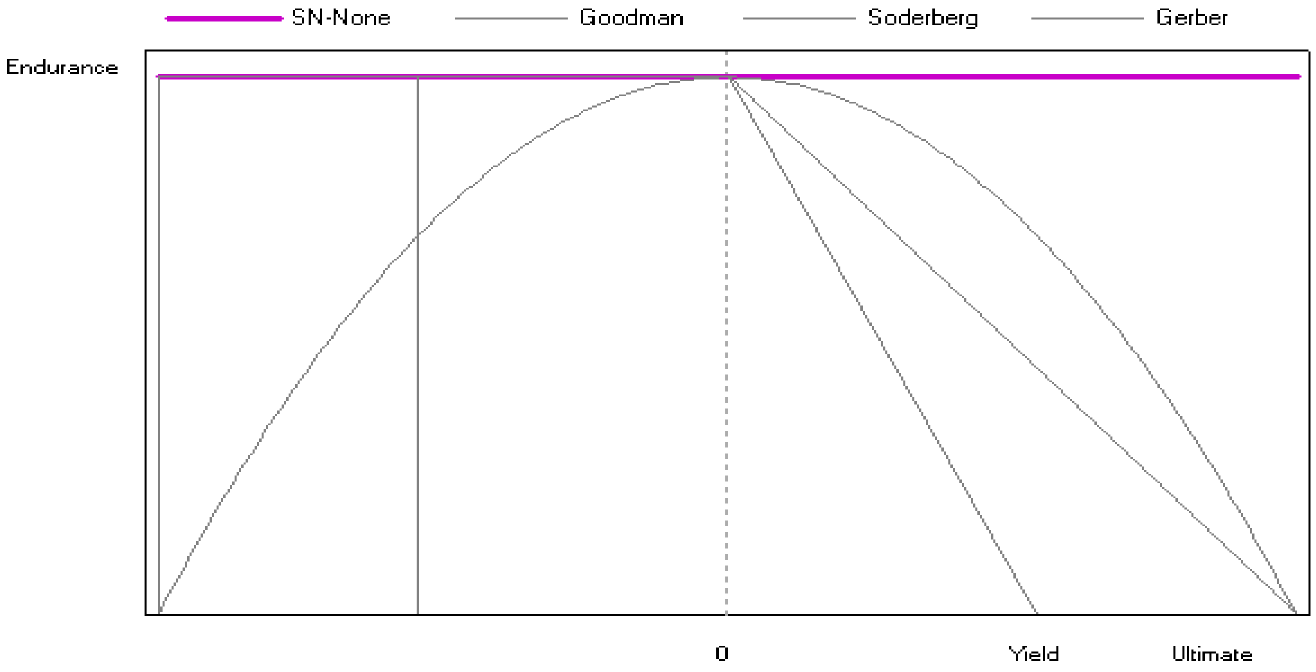
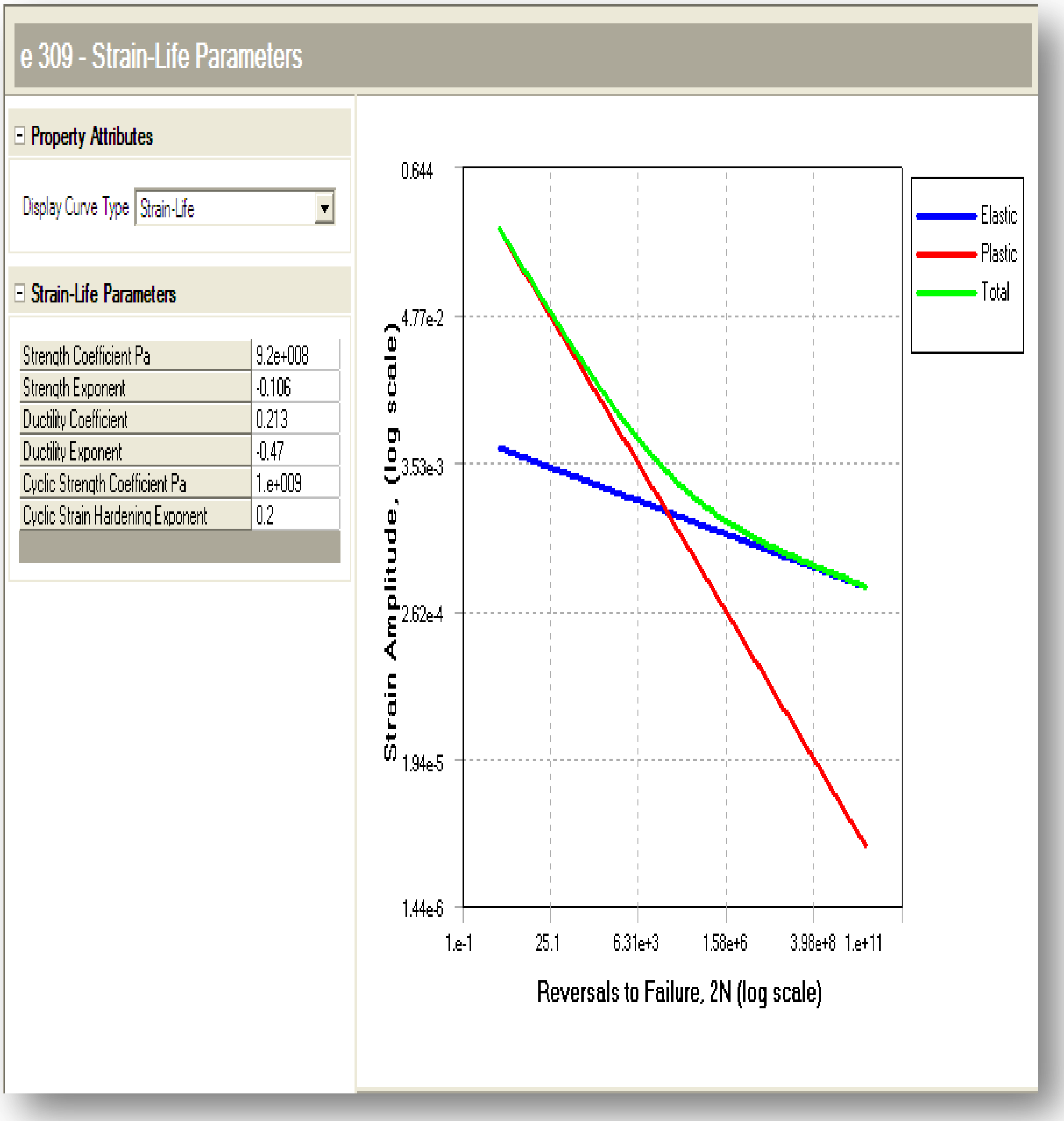


Fig.5.2.9.mean stress correction theory



e 309 - Strain-Life Parameters

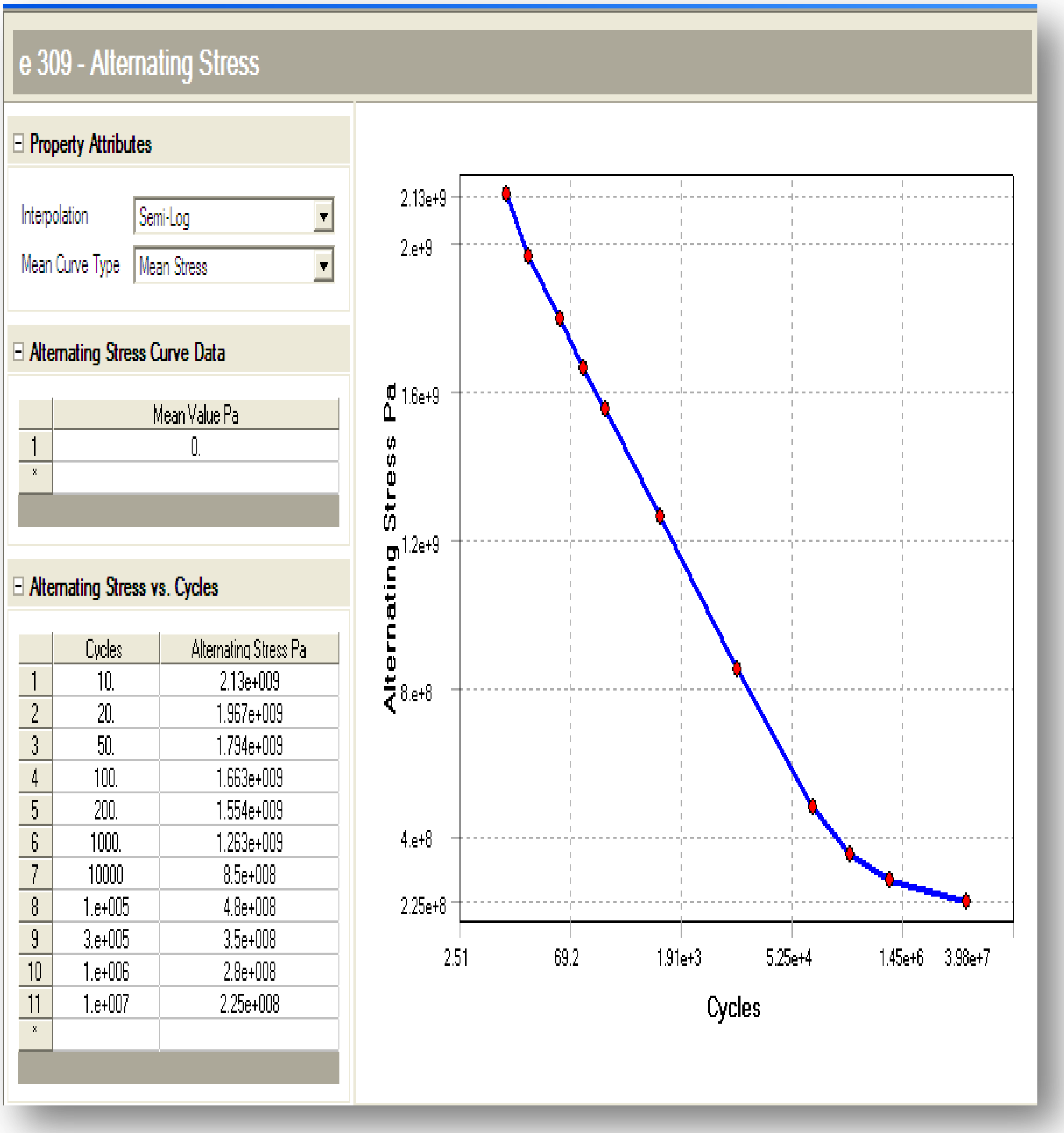
⊟ Property Attributes

Display Curve Type: Strain-Life

⊟ Strain-Life Parameters

Strength Coefficient Pa	9.2e+008
Strength Exponent	-0.106
Ductility Coefficient	0.213
Ductility Exponent	-0.47
Cyclic Strength Coefficient Pa	1.e+009
Cyclic Strain Hardening Exponent	0.2

Fig 5.2.9 Reversals to Failure, 2N (log scale)



e 309 - Alternating Stress

Property Attributes

Interpolation: Semi-Log

Mean Curve Type: Mean Stress

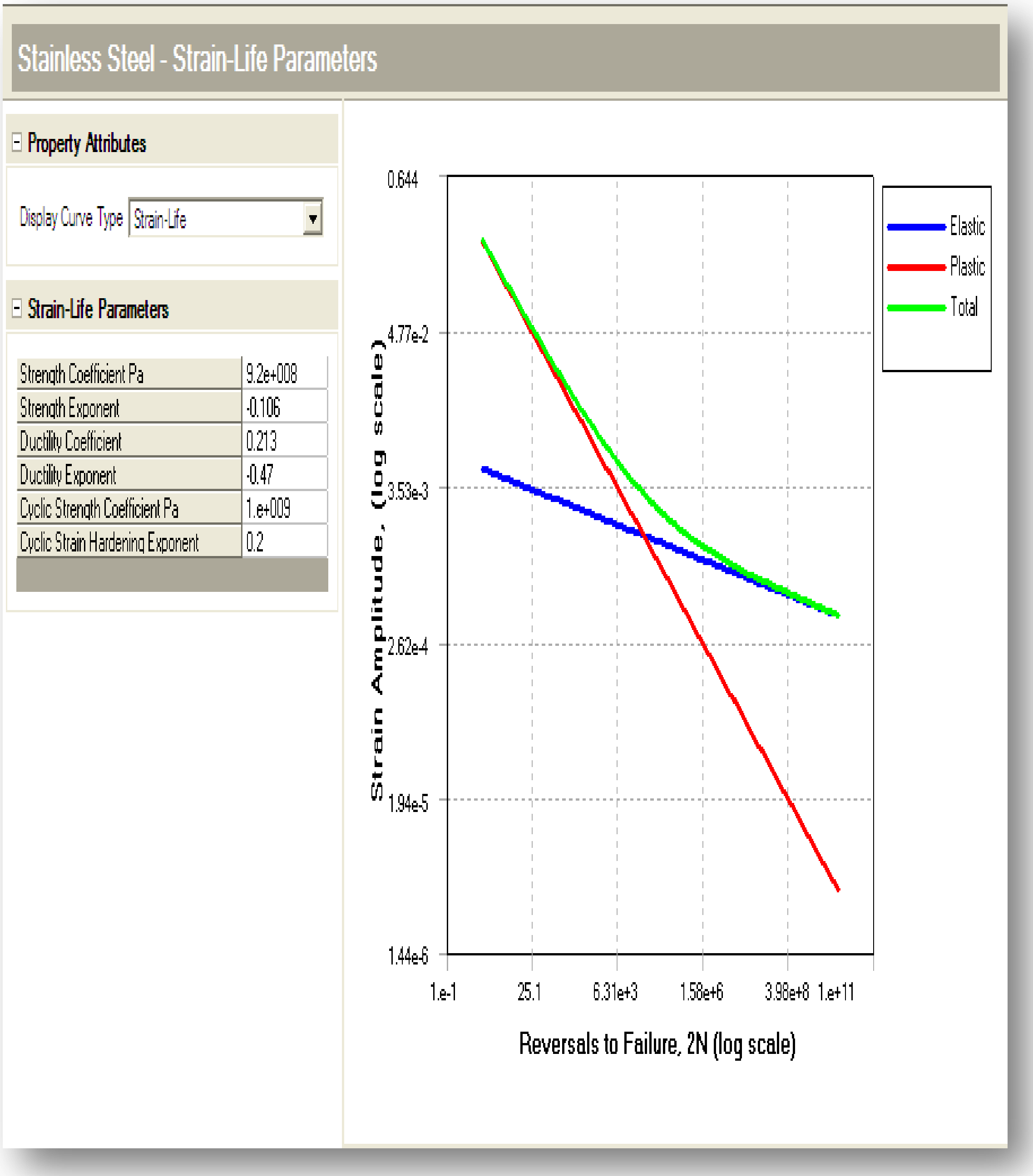
Alternating Stress Curve Data

	Mean Value Pa
1	0.
*	

Alternating Stress vs. Cycles

	Cycles	Alternating Stress Pa
1	10.	2.13e+009
2	20.	1.967e+009
3	50.	1.794e+009
4	100.	1.663e+009
5	200.	1.554e+009
6	1000.	1.263e+009
7	10000	8.5e+008
8	1.e+005	4.8e+008
9	3.e+005	3.5e+008
10	1.e+006	2.8e+008
11	1.e+007	2.25e+008
*		

Fig 5.2.10 Cycle



Stainless Steel - Strain-Life Parameters

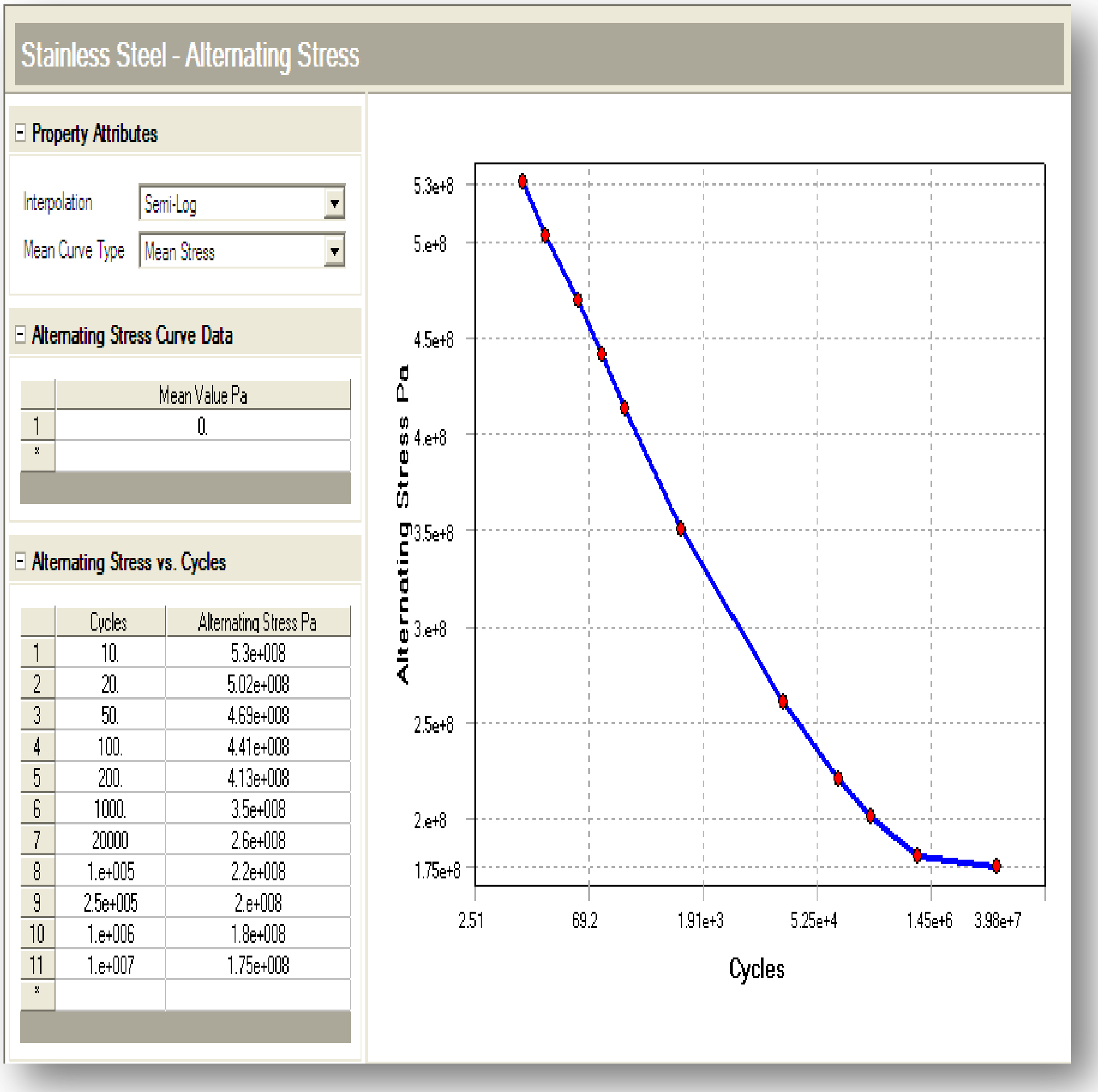
Property Attributes

Display Curve Type: Strain-Life

Strain-Life Parameters

Strength Coefficient Pa	9.2e+008
Strength Exponent	-0.106
Ductility Coefficient	0.213
Ductility Exponent	-0.47
Cyclic Strength Coefficient Pa	1.e+009
Cyclic Strain Hardening Exponent	0.2

Fig 5.2.11 Reversal to Failure, 2N(log scale)



Stainless Steel - Alternating Stress

Property Attributes

Interpolation: Semi-Log

Mean Curve Type: Mean Stress

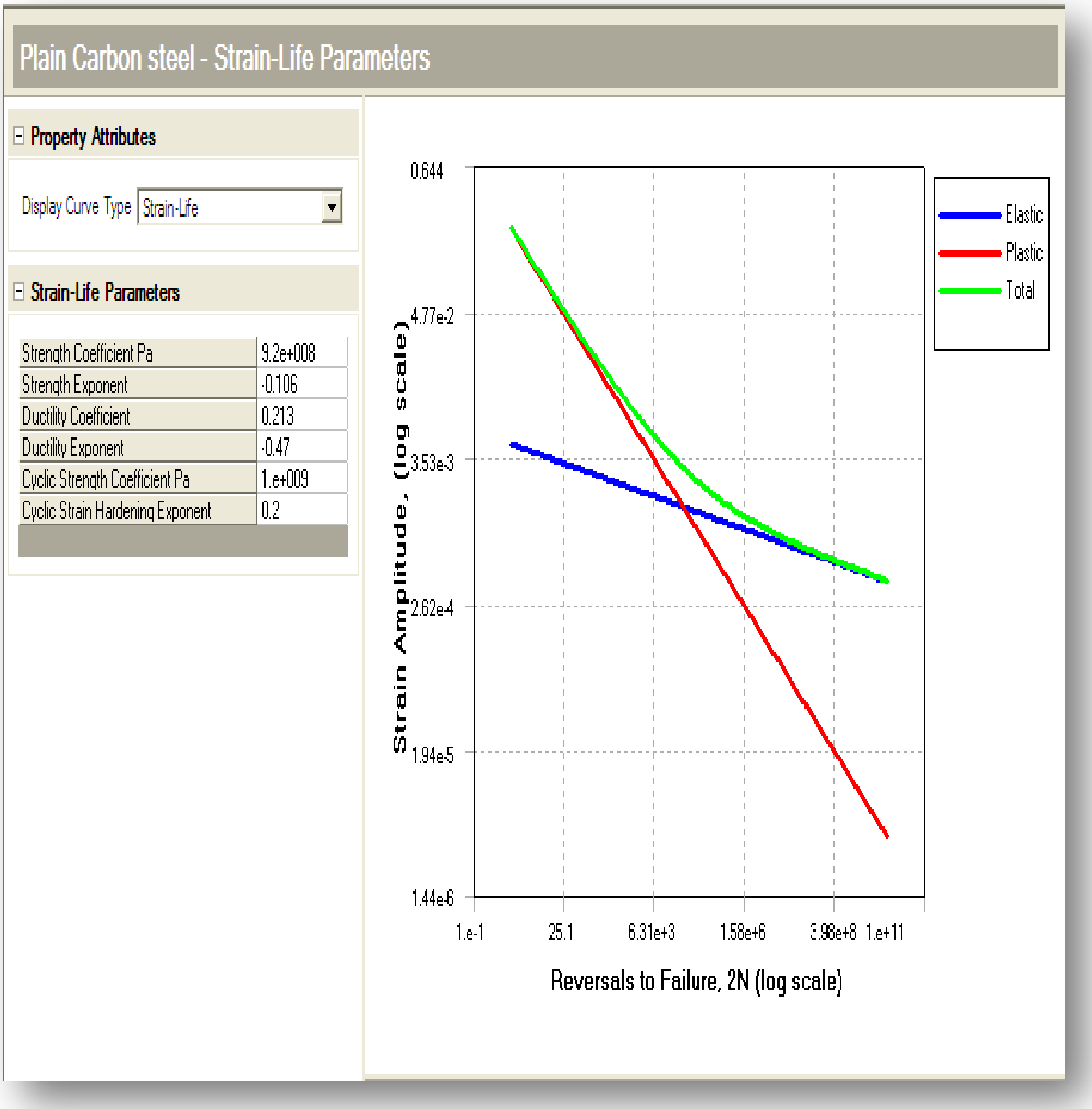
Alternating Stress Curve Data

	Mean Value Pa
1	0.
*	

Alternating Stress vs. Cycles

	Cycles	Alternating Stress Pa
1	10.	5.3e+008
2	20.	5.02e+008
3	50.	4.69e+008
4	100.	4.41e+008
5	200.	4.13e+008
6	1000.	3.5e+008
7	20000	2.6e+008
8	1.e+005	2.2e+008
9	2.5e+005	2.e+008
10	1.e+006	1.8e+008
11	1.e+007	1.75e+008
*		

Fig 5.2.12 Cycle



Plain Carbon steel - Strain-Life Parameters

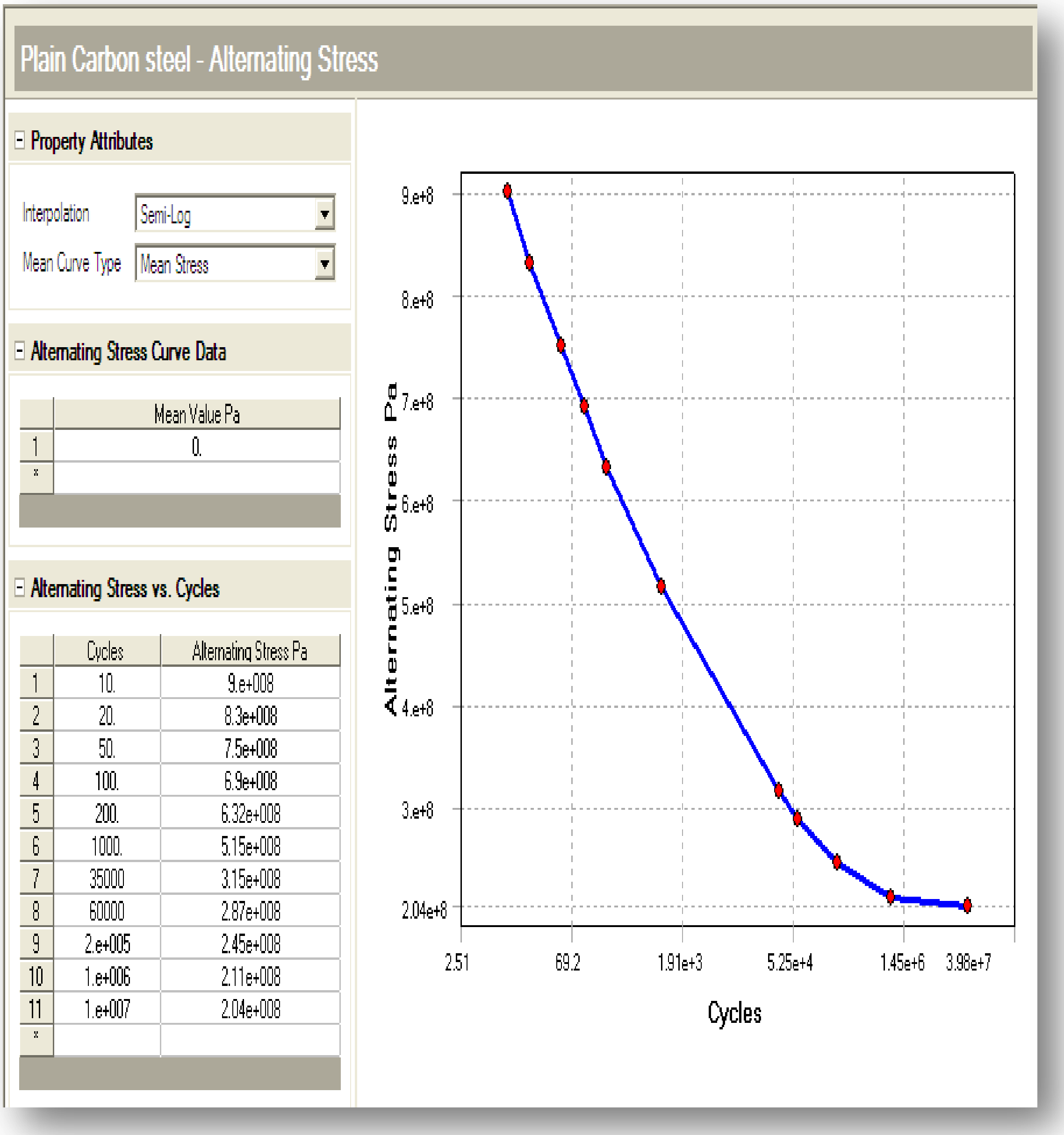
⊟ Property Attributes

Display Curve Type: Strain-Life

⊟ Strain-Life Parameters

Strength Coefficient Pa	9.2e+008
Strength Exponent	-0.106
Ductility Coefficient	0.213
Ductility Exponent	-0.47
Cyclic Strength Coefficient Pa	1.e+009
Cyclic Strain Hardening Exponent	0.2

Fig 5.2.13 Reversal to Failure, 2N(log scale)



Plain Carbon steel - Alternating Stress

Property Attributes

Interpolation: Semi-Log

Mean Curve Type: Mean Stress

Alternating Stress Curve Data

	Mean Value Pa
1	0.
*	

Alternating Stress vs. Cycles

	Cycles	Alternating Stress Pa
1	10.	9.e+008
2	20.	8.3e+008
3	50.	7.5e+008
4	100.	6.9e+008
5	200.	6.32e+008
6	1000.	5.15e+008
7	35000	3.15e+008
8	60000	2.87e+008
9	2.e+005	2.45e+008
10	1.e+006	2.11e+008
11	1.e+007	2.04e+008
*		

Fig 5.2.14 Cycle

Conclusion

1 – As the number of cycle increase the possibility of fatigue failure increases .

2 – Finite elements method can be used to predict the fatigue S-N curve for dissimilar welded joints .

3 – Finite elements method can be used to determine the effect of welding two different material with another filler material from the point of view of fatigue failure .

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