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Mechanical Properties Evaluation of Welded Joints of Stainless Steel 304L and Low Carbon Steel Using (TIG) Welding Techniques

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Abstract:
Stainless steels are widely used in, nuclear reactors, thermal power plants, vessels, automobiles components and heat exchangers for several industrial applications due to their superior fracture toughness, good inter granular corrosion resistance and non-requirement of post process annealing. The dissimilar metal joints of have been emerged as a structural material for various industrial applications which provides good combination of mechanical properties like strength, corrosion resistance with lower cost. Selections of joining process for such a material are difficult because of their physical and chemical properties. In this research study the effect of nickel alloy buffer layer (ERNiCrMo-3) on low carbon steel to evaluation mechanical properties of dissimilar metal joints welded of stainless steel 304L and low carbon Steel using (TIG) welding techniques. Specimens stainless steel of grades 304L was welded with specimen's low carbon steel by Tungsten Inert Gas (TIG) processes by Nickel alloy buffer layer first stage on low carbon steel and second stage without buffers layer. The process parameters like current, voltage, and weld speed, gas flow was putted. Tensile strengths of welded test samples with Nickel alloy buffer layer vary from 461 to 529MP depending upon the welding conditions. And is record the highest tensile strengths at 110A is 529MP and tensile strengths of welded test samples without buffer layer is record at 90A is 522MP. Depending upon the welding conditions. The results were compared for different joints welded it was observed that dissimilar metal joints by Nickel alloy buffer layer have better than without buffer layer and use special application. The microstructure was analysis and hardness were calculated and obtained good values.

Keywords: Low Carbon Steel, Tungsten Inert Gas (TIG), Nickel alloy, buffer layer, tensile strengths

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تقييم الخواص الميكانيكية لوصلات اللحام لمعدن الصلب غير قابل للصدأ 304L والصلب منخفض الكربون باستخدام تقنية اللحام (TIG)

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الملخص:
الهدف من الدراسة هي تقييم الخواص الميكانيكية للوصلات الملحومة لمعدن الصلب غير قابل للصدأ 304L والصلب منخفض الكربون ، لإيجاد أفضل بارامترات لحام التي تنتج أفضل خواص ميكانيكية تتناسب مع هذا النوع من المعدن ليتم استخدامه فيالمجالات الهندسية والتطبيقية ذات العلاقة.
وفي هذا البحث تم دراسة تأثير عمل طبقة رقيقة منمعدن سبيكة النيكل على أحد طرفي معدن الصلب منخفض الكربون المراد لحامه مع معدن الصلب غير قابل للصدأ 304Lبسمك 5mmللمعدنين، وإجراء عملية اللحام بسلك التغذية نوع (ER309L).
وتكون عملية اللحام على مرحلتين، المرحلة الأولى بعمل طبقة رقيقة (Buffer layer) بسلك من معدن سبيكة النيكل على أحد طرفي الصلب منخفض الكربون بسمك 5mm، ثم إجراء عملية اللحام مع المعدن الصلب غير قابل للصدأ304L بسلك التغذية نوع (ER309L).
والمرحلة الثانية تكون بإجراء عملية اللحام مباشرة بين المعدن الصلب غير قابل للصدأ304L والصلب منخفض الكربون بسلك التغذية نوع (ER309L)، وتم وإجراء الاختبارات الميكانيكية الشد والصلادة وإجراء الفحص المجهري على جميع الوصلات الملحومة وتحديد الأفضل ليتم استعماله في التطبيقات الهندسية المختلفة.

الكلمات المفتاحية: حديد منخفض الكربون، غاز التنسجتن الخامل، سبيكة النيكل، طبقة رقيقة، اختبار الشد

1. Introduction:

Stainless steels are widely used in, nuclear reactors, thermal power plants, vessels, automobiles components and heat exchangers for several industrial applications due to their superior fracture toughness, good inter granular corrosion resistance and non-requirement of post process annealing. The dissimilar metal joints of have been emerged as a structural material for various industrial applications which provides good combination of mechanical properties like strength, corrosion resistance with lower cost. Selections of joining process for such a material are difficult because of their physical and chemical properties. As the carbon percentage content rises, steel has the ability to become harder and stronger through heat treating; however, it becomes less ductile. Regardless of the heat treatment, higher carbon content reduces weldability. In carbon steels, the higher carbon content lowers the melting point[1].stainless steels, meaning those with a mixed microstructure of about equal proportions of austenite and ferrite, have the stainless steel is one of the most popular materials for structural applications, due to their excellent physical properties but increase the structural cost. The additional benefits and the design codes of stainless steels have focused their industrial use for conventional structural engineering applications such as civil construction, nuclear reactors, thermal power plants, vessels and heat exchangers for several industrial applications [1-5]. The better joint efficiency, simple process, low fabrication cost, welding reliability and efficient metal joining process are essential for production of many engineering and structural components. The metallurgical changes such as micro-segregation, precipitation of secondary phases, presence of porosities, solidification cracking, grain growth in the heat affected zone and loss of materials by vaporization are the major problems which produces poor mechanical properties in stainless steel welds. Therefore, for structural applications, the stainless steels are utilized efficiently by dissimilar steel welds between stainless and carbon steels with effective and economical utilization of the special properties of each steel dependent in the same structure. The joining of stainless steels with plain carbon steels is common applications in thermal power industries, stainless steel piping is often exposed to high temperature and pressure steam and carry on passes temperature and pressure may below a certain level, the low-carbon and low-alloy steels pipe line perform adequately and reduce the overall cost of the structure[2]. In study it was observed the Tungsten Inert Gas Welding is more suitable than Metal Inert Gas welding for dissimilar metal welding of mild steel and stainless steel, TIG welding process provides better strength. It may be because of less porosity in dissimilar metal welds during TIG welding. and carbon percentage of free carbon allows the product. Also in researches it was observed the stainless steel 304 can be welded to mild steel using either stainless steel welding electrode E308 or mild steel welding electrode by TIG welding, It was observed the tensile strength of welded samples using mild steel welding electrode were slightly lower than welded samples using stainless steel welding electrode, however, both types of welded samples exhibited optimum strength of the welded joint. All

welded samples fractured at mild steel base metal indicated the regions of stainless steel base metal; fusion zone and heat affected zone are stronger than mild steel base metal[3].
This study is concerned the effect of nickel alloy buffer layer on low carbon steel to evaluation mechanical properties of dissimilar metal joints welded of stainless steel 304L and low carbon Steel using (TIG) welding techniques.

2. Experiment Work:
2.1 Material specification:
2.1.1Sample preparation stainless steel:
A plate of material type ASIS304L was used for experimentation with length 180mm, width 80mm and thickness 5mm as shown in Fig. 1. And the chemical composition of the material is shown in the Table (1).

Figure1: Sample preparation stainless steel

Table 1: Chemical Composition of Base Metal 304L Stainless Steel (wt %)

Elements	Cr	Ma	P	Si	C	Ni	Mo	cu	Ti	w	Fe
%	0.12	2.196	0.693	0.028	18.8	9	0.148	0.14	0.34	0.139	69.9

2.2 Sample preparation low carbon steel
A plate of material low carbon steel was used for experimentation with length 180mm, width 80mm and thickness 5mm as shown Fig. 2, the chemical composition l of the material is shown in the Table (2).

Figure 2: Sample preparation low carbon steel

Table 2: Chemical Composition of Base Metal Low Carbon Steel (wt %)

Cr	Ma	P	Su	Cr	Ni	Si	Ni	Fe
0.02	0.92	0.016	0.014	0.034	0.029	0.212	0.0230	98.5

2.3 Welding parameter selection:
2.3.1 Welding parameter of Ni –alloy (NiCrMo-3):
The welding parameters of nickel alloy buffer layer on low carbon steels as shown in table (3).

Table 3: Welding Parameters and of Nickel Alloy Buffer Layer on Low Carbon Steels

Parameters type	Parameters Name	Symbols	Unit	Low	High
Fixed	Current	I	Ampere	100	
	Voltage	V	Volt	18	
	Gas flow rate	f	Liter/min	10	
	Welding speed	S	mm/min	160	

2.3.2 Welding parameters selected for TIG welding processes:

The Welding joints parameters of low carbon steel and 304L Stainless as shown in table (4).

Table 4: Welding Parameters of Low Carbon Steel and 304L Stainless

Parameters Type	Parameters Name	Symbols	Unit	Low	High
Variables	Current	I	Ampere	80	150
Fixed	Voltage	V	Volt	14	
	Gas flow rate	f	Liter/min	10	
	Welding speed	S	mm/min	180	

2.3.3 Welding process tungsten inert gas (TIG):

The specimens were turned in a milling machine and faced to prepare the weld surfaces. Further, debarring was done with emery paper and the surfaces to be welded were cleaned with acetone prior to welding.

Stainless steel of grades 304L was welded with low carbon steel by Tungsten Inert Gas (TIG) processes. First stage of welding joint by Nickel alloy buffer layer on low carbon steel and second stage without buffers layer as shows in Fig. 3a and Fig.3b respectively; the welding joint was designed single 'v' groove with angle 45°. The filler metal ER309L wire of 1.6mm diameter was used for all welding process, right welding progression was used for all joints.

The process Welding joints parameters selected for TIG welding processes are shown in the Table (3b).

(a) **(b)**

Figures 3: (a) welding joints with buffer layer, (b) welding joints without buffer layer

And the shielding gas pure argon was used of shielding gas is to protect the weld area from the contaminants in the atmosphere.

2.4 Sample preparation tensile:

Tensile testing to assess the influence of Nickel alloy buffer layer on Tensile strength, yield strength, and the percentage of elongation of all welding joints. Tensile testing was carried out using Universal Testing Machine of 400KN capacity. The crosshead speed was maintained at 70mm/min. Tensile test was carried out according to the ASTM standards. Properties that are directly measured via a tensile test are ultimate tensile strength, yield strength, maximum elongation. Samples of welded joints stainless steels 304Lwith low carbon steel as prepare specific dimensions.

2.5 Sample preparation of hardness:

The samples were cut from the welded specimens and using Rockwell hardness testing machine to determine the deference in hardness values across the weld joint at an interval of 0.3mm. Information about the metallurgical changes caused by welding.

The hardness measurements were performed to determine the strength, and the profile was carried out, where the different main areas of interest were identified, such as the fusion zone (FZ), (HAZ) and the (BM) as shown in Fig. 4 the trend of the hardness measurements obtained.

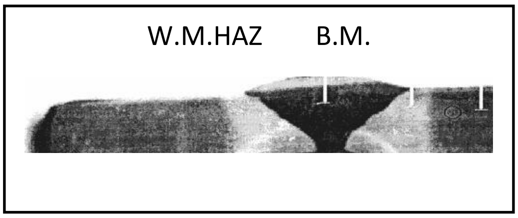


Figure4: Profile scheme of the hardness

2.6 Sample preparation Microstructure:

The macrostructure of metals and alloys consists of inhomogeneities on a fairly large scale; a macrostructure may also comprise other inhomogeneities, such as blowholes or porosity in cast or weld metal and flow lines in forgings. Specimens with length of 20 mm were cut from the welded joint; each specimen was carefully ground progressively abrasive paper in decreasing coarseness (grain size), the ground surfaces were polished using sand paper 80, 120, 320, 600, 1200.

3. Result and Discussion:

3.1Tensile properties:

Tensile testing was carried out using Universal Testing Machine of 400KN capacity. the crosshead speed was maintained at 70mm/min. Tensile test was carried out according to the ASTM standards. The tensile test welding of grades of stainless steels 304Lwith low carbon steel was carried out t for each welded sample. The ultimate tensile strength (UTS) will take as the maximum weld strength after which the weld will fracture. The samples tensile testes welding joints of dissimilar material with buffer layer and without buffer layer as shown in Figs 5a, b.

(a) **(b)**

(b) Figures 5. samples of tensile (a) with buffer layer (b) without buffer layer

The tensile strengths result of joints were evaluated, and the results of dissimilar welds material jointed welding with buffer layer and without buffer layer were obtained are tabulated in tables 5a, b and Fig's. 6a, b.

Table 5a: variation of average values of ultimate, yield strength with buffer layer

Test	Result				
SampleNo.	D	E	C	B	A
(I)	80	90	100	110	130
Tensile strength(N/mm)	488	519	509	529	524
yield strength(N/mm)	400	403	403	408	418

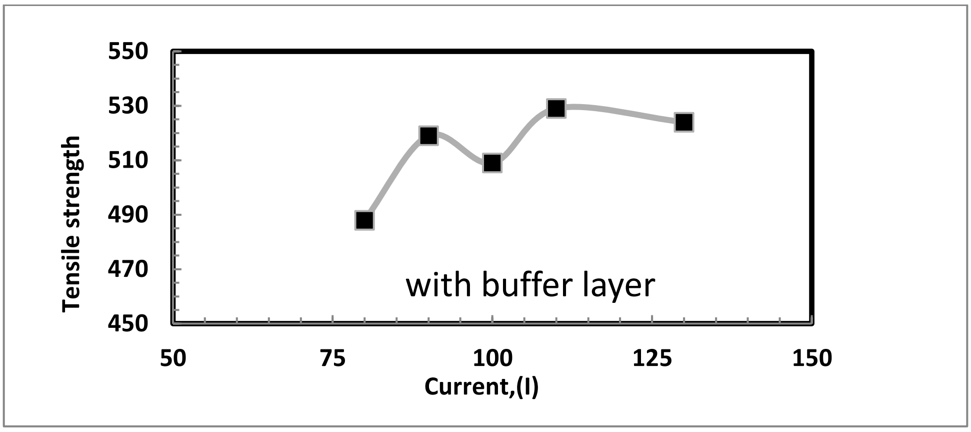


Figure 6a: Average values of ultimate tensile value with buffer layer

Table 5b. Variation of average of ultimate tensile yield strength without buffer layer

Test	Result				
Sample No.	1	5	4	3	2
(I)	80	90	100	110	130
Tensile strength (N/mm)	492	522	506	505	509
yield strength(N/mm)	440	430	437	391	450

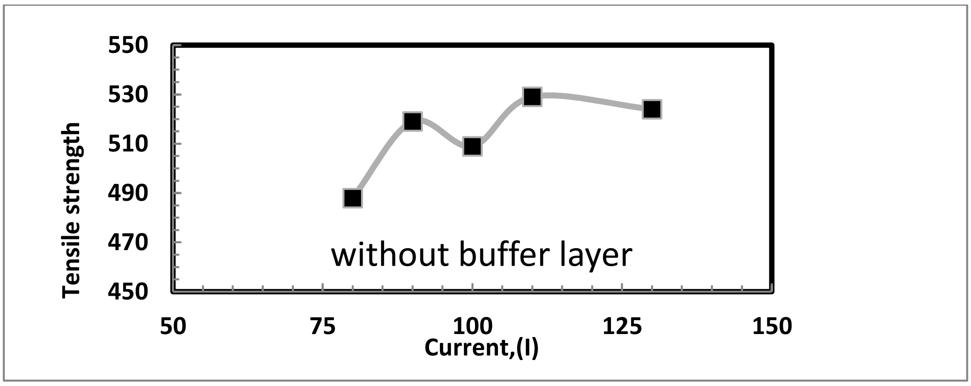


Figure 6b: Variation of average ultimate tensile value without buffer layer

Tensile strengths of welded test samples with Nickel alloy buffer vary from 461 to529MPa depending upon the welding conditions, and is record the highest tensile strengths at 110A is 529MP. Tensile strengths of welded test samples without Nickel alloy buffer vary from 492 to 509MP depending upon the welding condition and record the highest tensile strengths at 90A is 522MP. The expose samples for more levels of high degrees and ripped cold results excess strength tensile and hardness. The tensile specimens with and without Nickel alloy buffer layer broken in low carbon steel base metal to ensure pass processes welding and use in field engineering application were compared the results for different welded joints it was observed joints with Nickel alloy buffer layer slightly more increase and use in special field engineering application.

3.2 Hardness properties:

Hardness value of the welded zone was measured for all the welded specimens at the cross section to understand the change in mechanical property of the welded zone. The hardness value at the welded zone taken from the center of the welding zone towards the base material for different samples with and without Nickel alloy buffer layer performed depending upon the welding conditions, and the values are tabulated in the tables6a, b respectively. The different main points of interest were identified, such as the weld metal (WM), (HAZ) and the (BM).

Table 6a: variation of average values of hardness value, with buffer layer

Sample (I)	BM		HAZ		WM
	SS304L	low carbon steel	SS304L	low carbon steel	
A 130	165	146	119	93	176
C 110	168	140	152	119	172
B 100	158	141	137	142	167
E 90	168	151	191	188	173
D 80	161	168	189	160	171

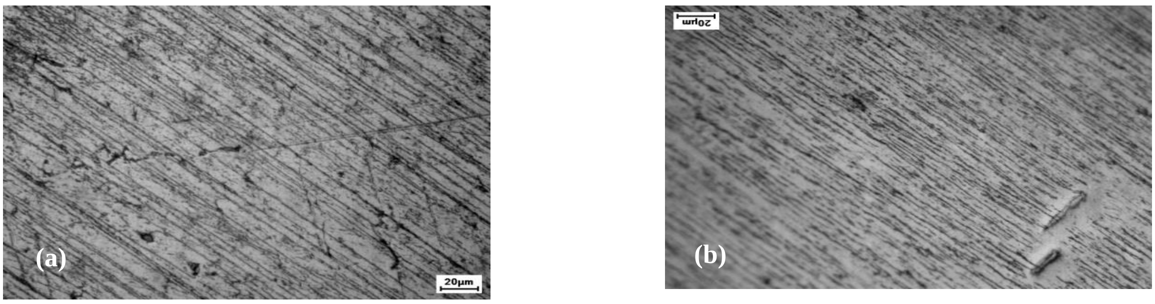
Table 6b: variation of average values of hardness value, without buffer layer

Sample (I)	BM		HAZ		WM
	SS304L	low carbon steel	SS304L	low carbon steel	
A 130	171	118	174	141	174
C 110	162	149	162	116	162
B 100	160	154	168	98	164
E 90	139	150	196	123	162
D 80	157	172	160	98	164

The expose specimens for more levels of high degrees and ripped cold results excess hardness, the results obtained and compared for different main points of interest were identified (WM), (HAZ) and the (BM), good values of hardness range have been obtained in all specimens.

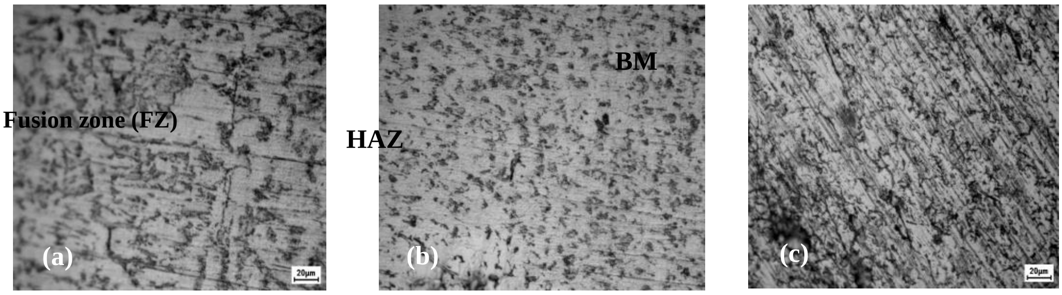
4.2 Microstructure:

Microstructure examinations of the welded joint specimens were carried out using Digital metallurgical microscope, the microstructure analysis was carried out at the (WM), (HAZ) and the (BM). The microstructure of low carbon steel base metal is appears as ferrite and pearlite and the base metal of 304L stainless steel appears as a uniform matrix of austenite grains also provide excellent corrosion resistance and good mechanical properties) are shown in Figs' 7a,b.



Figures 7: Microstructure of base metal of **(a)** low carbon steel and **(b)** stainless304l steel

Fig's 8 shows etched optical micrographs of WM and HAZ of (TIG) with Nickel alloy buffer at 110A respectively. It can be that etching allowed clear distinction between pearlite and ferrite phase in both WM and HAZ. The pearlite itself consists of bands of ferrite and cementite (or lamellar structure). Low carbon steel the amount of pearlite was keep decreasing with increasing of heat input for high carbon steel [2].



Figures 8: Microstructure of base metal of **(a**) (WM), **(b)** (HAZ)and(c) (BM) with Nickel alloy buffer.

Addition of nickel alloy buffer layer (ERNiCrMo-3) to prevents welding metal from corrosion and improve beside region welding point by cause inside effective, the microstructure of HAZ as Ferrite Island precipitates of carbides at boundaries in matrix of martensitic and retained austenite. The mechanical properties of welded material strongly influenced by microstructural features of weld section which is controlled by energy input and heat transfer rate. The microstructure (HAZ) revealed the structure consisting of more light areas of ferrite as matrix and dark area of pearlite in the grain boundaries on low carbon steel affected the microstructure of the WM by encouraging growth of dendritic solidification.

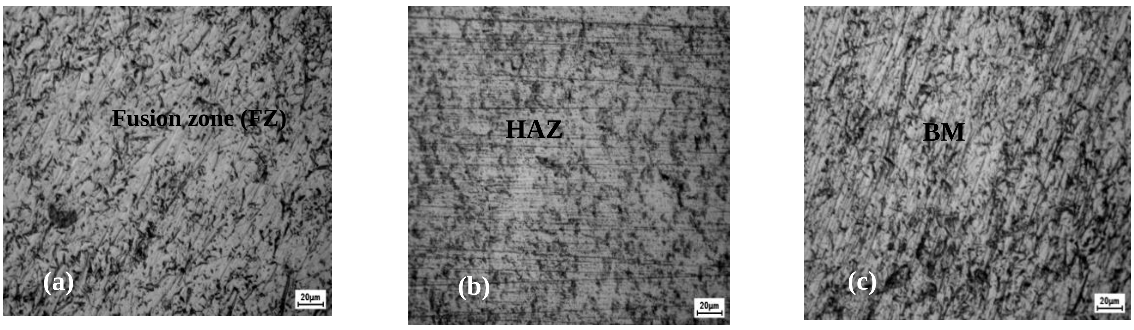


Figure 9: Microstructure of base metal of **(a)** (FZ), (b) (HAZ) and **(c)** (BM) without Nickel alloy buffer

Fig's 9b shows of WM and HAZ of (TIG) without Nickel alloy buffer, columnar in dendritic weld metal (WM), (HAZ) and (BM) continued dominating at all weld conditions however, at 90A, the grains showed a noticeable growth and larger spacing between dendrites as presented. The grain growth could be due to the relatively heat input of this condition. At the region adjacent to stainless steel 304L, skeletal ferrite was mainly observed for the different welding conditions. Many locations in the welding joints without Ni featured with presenting of cellular-type structure. The absence Ni increases encouraged cellular structure over dendritic [8, 9].

The evaluation of these mechanical properties can be done by conducting standard tests such as tensile, Additionally, microstructure and metallographic analysis may provide useful insights into the welding process and properties of the welded joint.

4. Conclusions:

The following conclusions were arrived at the end of study the experiment of TIG welding technique of stainless steels 304L with low carbon steel can be made evaluated mechanical properties:

- The TIG welded test sample with buffer layer has recorded good ultimate tensile stress, then without buffer layer ultimate tensile stress.
- The results were compared for different joints welded it was observed that dissimilar metal joints by Nickel alloy buffer layer have better (slightly more increase) than without buffer layer and use in special field engineering application.
- Welded samples have shown tensile properties comparable to base Indicating good weld quality joints.
- Welding strength or tensile strength of the weld joint depends on various factors parameters such as like welding speed and welding current.

- Hardness value range obtained good in all specimens improve mechanical properties.
- Addition of nickel alloy buffer layer (ERNiCrMo-3) on low carbon steel affected the microstructure of the WM by encouraging growth of dendritic solidification and improve beside region weldin point by casue inside effective.

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