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COMPARATIVE STUDY & ANALYSIS OF WELD STRENGTHS OF SPOT & HYBRID LASER - MIG WELDING ON LAP JOINT

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ABSTRACT

Lap Joint with fillet weld under eccentric loading is used to compare the twowelding processes. In high strength steelsheet, witha ferrite- martens ticmicrostructure was subjected to Hybrid Laser - MIG &Spot Welding. The selection of different parameters&strength of Heat Affected Zone in tension, shearing &bending etc. is discussed &comparison of the resulting microstructure &mechanical properties obtained with both hybrid laser Arc welding &spot welding processes ismade. It was found that a hardness drop might - occur in the Heat Affected Zone due to tempering of the marten site in the base material microstructure, leading to strengthdecrease and localized deformation during tensile testing. Finally, the appearance of hot cracks occurring in the hybrid laser welds isstudied.

From the simulationand experimental along with theoretical results obtained it is observed: -

(a) *A satisfactory agreement among experimental, theoretical & simulationresults has been observed in case of spot welding process. Inspot weld " buttonfracture" seem to be proportional to the strength&thicknessof sheets &nuggetdiameter.*

(b) *) The experimental & simulatedvalues are slightlydifferent due to large controlling parameters in case of hybrid welding, which has been verified theoretically based on maximum strain energy theory with energy correctionfactor.*

(c) *) Use of inappropriate fillermaterial in combination with low heat input might lead to excessive weld metalhardness.*

(d) *)Hot Cracks were not found at the lower welding speed.*

(e) *) The fractureoccurred outside the weld zone in caseof hybrid welding, which was consistent with the literature.*

(f) *Hybrid welding process is a very interesting process in order to improve capabilities, increased welding speed &improve joint mechanical properties.*

(g) *)The fracture in both the welds occurred from the region of HAZ.*

(h) *) The spot welded specimens were broken inthejoint. The strengthof the weld is higher than the strengthof the metal plate, which is the reason of why hybrid welded specimens were broken in the thinnerplate.*

(i) *) For same nugget diameter weld strength increases withincreasein thickness.*

This thesis presents an investigation about hybrid laser welding &spot resistance welding in construction steels. Lap joint is used in all the experiments in order to compare different processes. FEM models of Weldingsare also compared with result frommechanical tests &analytical/ empirical values. Macro &Micro Examinations, hardness tests, tensile tests &bending&shearingtestswerecarriedoutinordertoperformthisstudy.

INTRODUCTION

Manufacturing economy to a large extent is based on fabrication cost & its strength of efficiency of welding. Welding Technology is one of the measures of industrial & thus global value of any country. Our present work is about hybrid-laser welding & spot welding in structural & machine parts construction using steels. Hybrid Laser Welding is a technique that combines a laser and electrical Arc Welding. In order to investigate, the behaviour of this welding process, specimens were carried out with different parameters. Three-Four Tests destructive and not destructive, were made and hence to gain knowledge about the relations between joint geometry and welding properties. Furthermore, hybrid welding joints in order to understand the mechanical properties. In the process, heat, momentum and molten filler material are transferred to the welding zone by the MIG/MAG process in order to enhance the action of the deep penetration welding laser beam. The penetration is determined by the laser alone, and are maintains the welding speed, even in the case of large gap. Hybrid Laser Welding is the combination of a laser welding & an ARC Welding process, acting simultaneously in the same process zone. This technique was developed originally by Prof. Steen & Co-Workers at Liverpool University in the late1970s.

Various Hybrid Laser Welding processes exist, depending on the combination of the specific laser source (CO2, Nd : YAG Fibre Laser, Disc Laser) and ARC Welding process (MIG, MAG, TIG, PAW). In this investigation a 4 KW Welding machine has been used.

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The Laser Beam creates vapour capillary, due to its very high energy density of more than 106 Watt / Cm2, the so called "Keyhole", which enables a deep welding effect where the beam energy is absorbed throughout the workpiece depth. A electric arc is created between the MIG Wire (the anode) & the work piece (the Cathode). The Arc (104 Watt /cm2 the energy density) melts the feeding wire. Droplets are detached & transferred to the workpiece to fill any gap and to create the desired weld shape. Vaporisation not only take place due to the laser, but also from the welding wire, so more metal vapour is available. The metal vapour escaping from the vapour cavity acts upon the ARC plasma. Absorption in the processing plasma remainsnegligible.

Design of Hybrid Laser MIG Welded Fillet Joint:

Few terms are used while designing a filled weld as follows:-

Size of Filled Weld.

The length of the sides of the largest right-angles triangle in the cross-section of the filled weld is denoted as the size of filled weld as shown in Table 3. Usually, the perpendicular sides of such a right-angled triangle are equal and the size of a fillet weld may be specified by one dimension only. The size of the fillet weld should not less than the minimum values given in Table 3* as per I.S. 816-1969.

Maximum size of fillet weld = t - 1.5 mm

Where, t = Thickness of edge to be welded.

Table 1

Thickness of Thicker Part	Maximum Size
Up to and including 10 mm	3mm
Over 10 up to and including 20 mm	5 mm
Over 20 up to and including 32 mm	6 mm
Over 32 up to and including 50 mm	18 mm minimum

The maximum size of the filled weld is also specified. The maximum size of the filled weld applied to the square edge of a plate or shape should be 1.5mm less than the normal thickness of the edge. The size of the filled weld used along the toe of an angle or the rounded edge of a flange should not exceed three-fourths, the nominal thickness of an angle or flange leg.

Throat of filled weld.

The throat of a filled is the length of perpendicular form the right-angle corner to the hypotenuse as shown in Table. The effective thickness of throat is calculated as: - **Throat Thickness = k x fillet size**. The value of k depends upon the angle between the fusion faces as given table. Here in hybrid weld **k = 0.78 for angle of fusion 45º.**

Table 2

Values of k

Angle between fusion faces	**450º - 60º**	**60º - 90º**	**91º - 100º**	**101º - 106º**	**107º - 113º**	**114º - 120º**
Constant k	0.78	0.7	0.65	0.6	0.55	0.5

Effective Length of Fillet Weld.

The effective length of a fillet weld is equal to its overall length minus twice the weld size. The effective length of a filled weld designed to transmit loading should not be less than four times weld size. Only the effective length is shown on the drawing and the additional length (i.e. 2 x weld size) is provided by the welder. **Effective Length > 4 x weld size = overall length - 2 x weld size.**

End Return.

The fillet weld terminating at the end or side of a member should be returned around the corner whenever practicable for a distance not less than twice the weld size shown in Fig. A to C or Fig.

This provision applies in particular to fillet welds in tension connecting beam seatings, brackets etc.

Overlap.

The overlap in a lap joint should not be less than five times the thickness of the thinner plate as shown in Fig. A to F or Fig. 3

$$L < 5\ x\, t$$

Side Fillet.

In a lap joint made by a side or longitudinal fillet weld the length of each fillet weld should not be less than the perpendicular distance between them, the perpendicular distance between the side fillets should also not exceed sixteen times, the thickness of the thinner part connected. Therefore, in Fig. t < b and b > 16t, where t = thickness of thinner plate. If b exceeds this limit, the end fillet, plug weld or slot weld is provided in addition to prevent buckling or separation of theparts.

Lap Joint:

In welded joints, two components may be under the direct control of the designer, the weld type and the joint type. There are several different techniques for joining two pieces of material. Examples of these techniques are butt joints, lap joints, corner joints, edge joint and tee joints. In accordance with the joining type designed, the weld will have different properties.

ARC Welding:

There are three different groups of ARC Welding processes:-

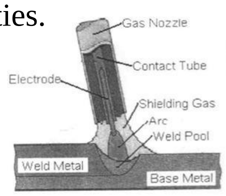

Fig. 1 : **MIG Arcwelding**

01. Shielded Metal ArcWelding(SMAW)

02. Gas-Shielded Arc Welding, including Metal Inter Gas (MIG), Metal Active Gas (MAG) and Tungsten Inert Gas(TIG).

03. Submerged Arc Welding(SAW).

LASER WELDING

Over the last years, Laser Welding has become a widely accepted as joining method, due to it offers several advantages as compared to other welding techniques, as soon as it is a good choice when classical joining methods are notsuitable.

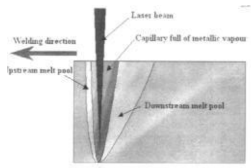

Fig. 2 : Schematic of the Laser Welding

Laser Welding is a key whole fusion welding method, which is obtained by a high power density, Laser Power is often in the range of 0.3 to 3KW for Nd: YAG Laser & 5-10 KW for CO2 Laser, achieved with focusing a laser light beam to a very small spot. The focused power has the max energy density as 106 W/Cm2.

Theoretically, the focused spot size "d" of a laser beam is given by:-

d = f . □ also

PD □ 4p1v2/ f2a where

f	=	Focal Length of the lens.
□	=	Full angle beam divergence.
PD	=	Power Density.
V	=	Wave Length of Laser Radiation.
a	=	Characteristic Dimension of Laser Radiation.

Hybrid Welding:

Laser Welding has important drawbacks specially related to ability to bridge a gap. These limitations can be solved by the combination of Laser Welding with ARC Welding. This technique was invented in the 1970's & developed in Laboratories all over the world. The first industrial Laser MIG Hybrid System was put into operation in the year 2000 at the factory of an oil tank manufacturer. After that, several installations followed it in the automotive industry, ship building & tubeproduction.

In the process, head, momentum & molten filler material are transferred to the welding zone by the MIG/MAG process in order to enhance the action of the deep penetration welding laser beam. The penetration is determined by the laser alone, and the arc maintains the welding speed, even in the case of large gap.

Defects in Welded Joints

With the correct welding conditions, techniques and material quality standards, the welding processes will yield a very high quality weld result. However, some welding defects can form when welding. The presence of these defects generates a significant weakening of mechanical properties of welded structures. Defects usually found include incomplete penetration, incomplete fusion, undercutting and porosity.

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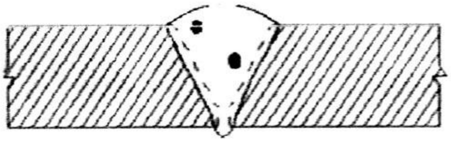
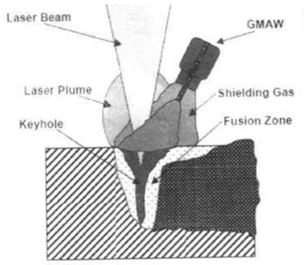


Fig. 3 : Porosity



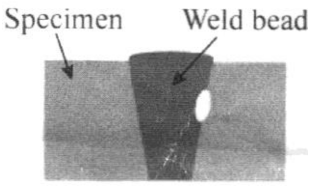


Fig. 4: Lack ofFusion

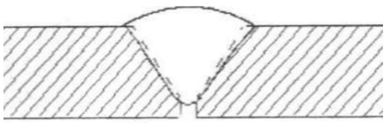


Fig. 5 : Incomplete Penetration

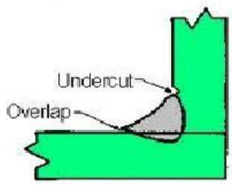


Fig. 6 : Undercut in welded joints

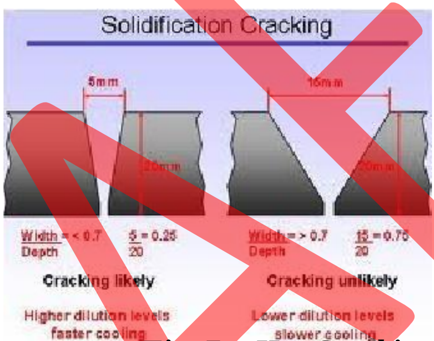


Fig. 7 : Hot Cracking

Post weld Thermal Treatment

- Stress relief heat-treatment is defined as the uniform heating of a structure to a suitable temperature, holding at this temperature for a predetermined period of time, followed by uniform cooling (uneven cooling may result in additional stresses).

- Stress relief heat treatment is usually performed below the critical below the critical range so as not to affect the metallurgical structure of thework.

- The percentage relief of internal stress depends upon the type of steel (its yield strength). The effects of varying time and temperature areshown.

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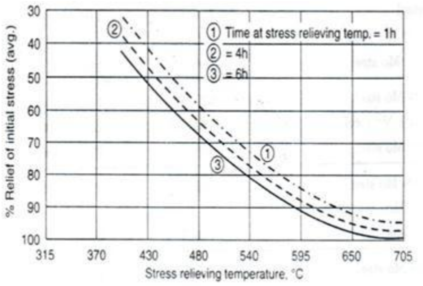


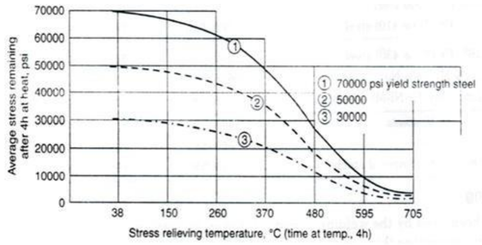


Fig. 8 : Effect of Temperature & Time

OBJECTIVES

For robust manufacturing control & racy increased of efficiency, a learning feed ward and feedback control strategy will need to be imposed to restrict the cost, quality & quantity collisions. In particular, a feed forward scheme will be required to adapt to different or changing system parameters. For example, during the fabrication of the mechanical units, there will obviously be save fabrication tolerance of welding. In addition, other parameters are also required to control to achieve the required weld strength, in contrast to the rapid production along with quality &quantity.

In our thesis, Hybrid-Welding (Laser-MIG Welding) is compared with spot welding process. The analysis of thesis has been divided into three parts as:-

01. Theoretical Analysis ofWelds.
02. Practical Analysis ofWelds.
03. Simulated Test (FEA) ofWelds.

The above three values of weld strengths are compared with satisfactory reason of differences.

The Hybrid & Spot welded specimen were tested for weld hardness, microscopic study of grain structures of welds, Tensile strength of welds & weld strengths under eccentric loadings.

Also the strengths of welds under tension & bending of using strain energy has been verified with corresponding simulation test values of the welds; resulting the empirical relation between weld strength & thickness of joint.

The part of the extended work of

01. Alberto Jose PegoFernandez, Lulea University of Technology, Department of Applied Physics &MechanicalEngineering.
02. Mr. MinhajAlam(The Ph. D. Student) from Lulea TekniskaUniversitet; Division of Manufacturing SystemsEngineering.

MATERIAL & SPECIMEN PREPARATION

Two varies of structural steels (steel 1 & steel 2) given in the table 1, were prepared with sin specimen as S1A, S1B, S1C for Steel 1 & S2A, S2B & S3B for Steel 2. For Hybrid Welding Process a large number of parameters were required to set as power, welding speed, laser type, beam orientation etc.

With high laser power penetration of weld increases with in welding speed weld penetration decreases. The economical angle of the torch is 40º to 50º with the surface of the work piece.

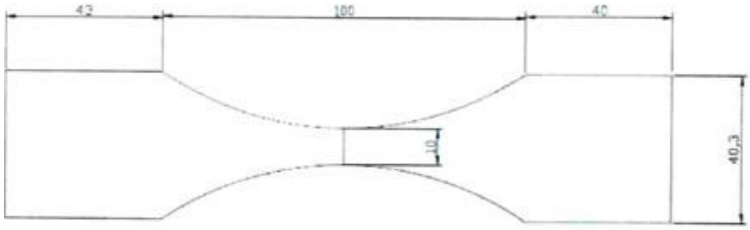


Fig. 15: Hybrid Welded Specimen

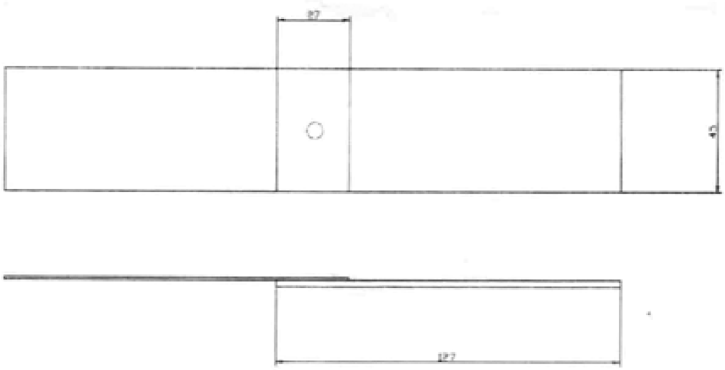


Fig. 16: Spot Welded Specimen

Laser Conditions:-

Laser : Rs. 6,000 Nd:YAG

LaserPower : 5000 Watt.

Focus Point : On the materialsurface.

MIG Conditions:-

Equipment : ESAB - ARISTO

LUD 450 W /MEK44C

MIGVoltage : (30 - 50)V

WireFeed Rate : .5 - 20m/min

WeldingSpeed : 2.5 to 5 m/min

PulseCurrent	: (32)Ampre
PulseFrequency	: (120 - 130)Hz
PulseLength	: 2 MS
BackgroundCurrent	: (60 - 72)Amp.
ShieldGas	: 65% He, 30% Ar, 5% CO_2, 241 /Min.
ElectrodeWire	: OK1251, 1 to 3 mm dia.
FillerMaterial	: G2Si1

Properties of Spot Welding

ElectrodeTip Diameter = 8 mm to 12 mm

WeldingTime = 15 to 30Cycles.

WeldingForce = 5.6 KN to 8KN

Gap = 1 mm to 2 mm

SurfaceEnergyAbsorbed= 1.8 J/Min^2 to $4J/mm^2$.

ArcEnergy = $\frac{V \times I \times 60}{v \times 1000}$ KJ / mm

V	=	mm / min	=3.5 mm /min
VI	=	Voltage	=10 to 300 KVA (25 KV forS1B)
I	=	WeldingCurrent	= 25 to 50 Amp. (40 Amp for S1B)
T	=	Temperature of weldzone	
	=	815° C to 930°C	

Dia of Spot of Electrode=8 mm to 12 mm= (6.6 mm for S1B)

There should be increased voltage of arc for wider fit-up gaps to avoid lack of fusion with given wire diameter & arc voltage increase in welding current gives deeper weld. Pulse modes of arc welding source reduce the spatters maintaining the penetration of the weld. The shield gas is generally argon or helium. The sample preparation required Joel Electron microscope with 10 x magnification to visualise the microscopic features of the structure of material under study. Processes post welding has been divided into following steps are Cutting, Mounting, Planar Grinding, Fine Grinding, Polishing & Etching.

Cutting has been performed an cutting-wheel with small abrasive particles, in order to produce a fine surface and a minimum deformation. Cooling is dared to avoid structural charges by heat. After cutting, the sample is mounted with a phenol powder, which makes the sample easier to handle & to protect edges to reinforce weak or porous material.

Grinding paper is used to carry out the planner grinding. After grinding & washing the samples polishing is done. Finally, etching with 3% Nital is used to eliminate marks from stains. Now, the samples are ready to perform macro & micro examination on optical microscope.

Macro Examination

Macro Examination is a method of examination of large regions of the specimen surface or fractured section with the naked eye or under low magnification. During the examination, any defects on the sample may be assessed, as slag, porosity, lack of weld penetration or lack of sidewall fusion. As well as defects, is possible to determinate a large number of features, including weld runsequence.

Micro examination is carried out for several purposes; the most clear is to analyze the structure of the material. It is also common to examine for metallurgical anomalies such as excessive grain growth, third phase precipitates etc. This process is performed with a optical microscopy with a high magnification.

Hardness Test

Hardness is a property of a material that enables it to resist plastic deformation, usually by penetration. Hardness is not an intrinsic property of the material. The value of this property is the result of a defined measurement procedure, thus depending on the hardness method used, the hardness value will be different.

All of the hardness tests involve the use of a specifically shaped indenter, significantly harder than the test sample. This indenter is pressed into the surface of the sample using a specific force. Either the depth or size of the indent is measured to determinate the hardness value.

Hardness measurements are widely used for the quality control of materials because they are quick and considered to be non-destructive tests when the marks or indentations produced by the test are in low stress areas.

In the thesis Vickers Hardness Test has been used.

Vickers Hardness Test:

Vickers Hardness is a measure of the hardness of a material, calculated from the size of an impression produced under load by a pyramid-shaped diamond indenter. This indenter is a square-based pyramid with an angle of 136º between opposite faces. The two diagonals of the indentation left in the surface of the material after removal of the load are measured using a microscope and their average calculated. The area of the surface of the indentation is calculated. The Vickers Hardness is the value obtained by dividing the kg load by the square of indentation. Load time is around 30 seconds.

To cover all testing requirements, the Vickers test has two different force ranges, Micro (10g. to 1000 g.) and Macro (1Kg to 100kg).

The advantages of the Vickers Hardness Test are that extremely accurate measures may be taken, and just one type of indenter is used for all types of metals and surface treatments.

Vicker's Hardness Value of weld is given by :

$$HV = \frac{\text{AppliedLoad}}{\text{AreaofIndentation}} = 2\,F \sin\left(\frac{136^{o}}{2}\right) / d^{2}.$$

$$= \mathbf{1.854F/d^{2}.}$$

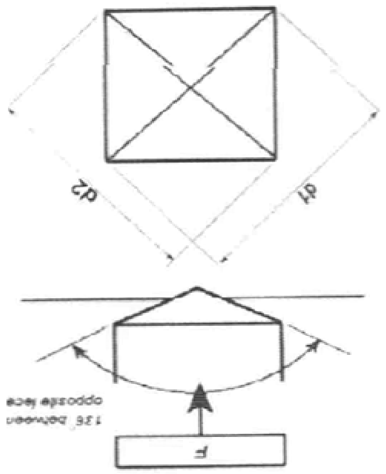


Fig. : HardnessTest

Table(a)

HardnessMeasurement

(Hybrid Laser WeldedSpecimenS2B)

S. No.	Vicker's Hardness Value (HVS)	Distance across the weld from one Face (mm)
1.	653	1
2.	633	2
3.	656	3
4.	656	4
5.	595	5
6.	574	6

Table (b)

Hardness Measurement

(Spot Welded SpecimenS1B)

S. No.	Vicker's Hardness Value (HVS)	Distance across the weld from one Face (mm)
1.	593	1
2.	617	2
3.	622	3
4.	656	4
5.	674	5
6.	692	6

This lower value is **574 HV** and it rises until 692 **HV**. It may be explained, that the first point is so close to the boundary of the steel sheet. Since, this point, the hardness rises, while the indentations are approaching to the weld nugget. After that the values are approximatelyconstant.

Tensile Test:

Tensile Tests were carried out to know the tensile stress, that the welding can withstand. All the hybrid welded specimens were fractured in the base metal. This is because the tensile strength is higher in the weld than in the base metal.

Table - (c)

Specimen	Field Type	Load (KN)	Thinner Plate	Voltage (V)	Current (A)	Feed Rate
S1 A	Hybrid		Steel 2	38	140	5.0
S2 A	Hybrid	-	-	-	-	-
S1 B	Spot		Steel 2	38	40	8.5
S2 B	Spot	-	-	-	-	-

Microstructure of Laser Hybrid Weld :

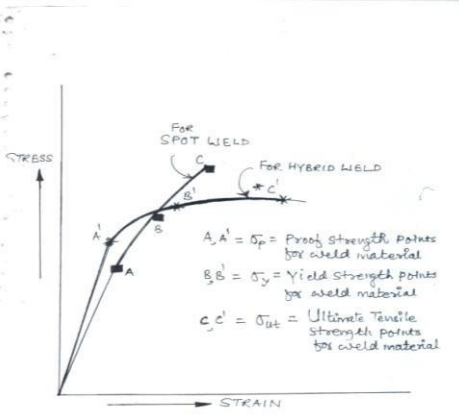
To find out the Heat Affected Zone and understand the properties that it prevents, an investigation of the microstructure was carried. The Heat Affected Zone in laser hybrid welding joints may be found by analyzing the hardness curve. This curve changes severely at the beginning of the Heat Affected Zone. This is because the change undergone by the microstructure. The magnification of all the pictures is10Aº.

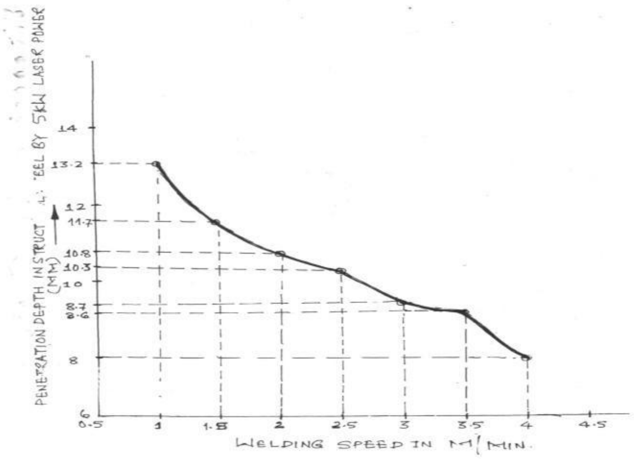
Spot welded sample has a higher hardness values (both maximum and minimum) than hybrid welded samples in Heat Affected Zone.

As, in tensile test, the strength of the weld increase in proportion to the weld bead width.

It is also possible to see the tensile strength in hybrid welded samples presents a relationship with MIG parameters. When we increase MIG parameters, such voltage, current or wire feed rate, tensile strength shows a higher value.

All the hybrid welded specimens were fracture roughly at the same distance of the weld bead, except the sample S1A. After analyzing the features of the process, I think that the location of the failure corresponds more with a random phenomena than with physical nature of the weld.





Comparative Strength Analysisof Welds. From Distortion Energy Theory applied to weldstrength

k_f = Energy Correction Factor for HybridWeld.

= 1.5 to 1.68

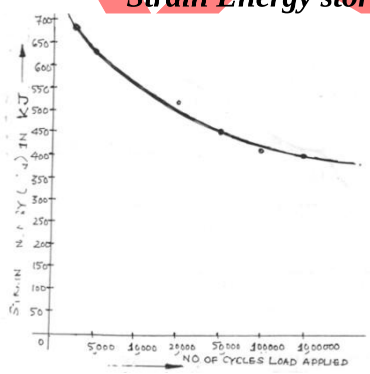
□ = Strain Energy stores in the weld due to loadW.

= $\{ k_f C^2_{max} / 4N\}$ x Volume of Weld Material +$\frac{W.e.l}{2EI.k_f}$.

Where,C_{max} = Max.Shearstrength,N=ModulusofRigidity

E = Modulus of Elasticity of parent material to bewelded

Strain Energy stores v/s. No. of Cycles Load applied



RESULTS &DISCUSSION

Comparing the Vickers hardness tests of sample, we can see that hardness values are approximately same in bothwelds.

The use of low values of current, voltage and wire feed increases the probability of defects in the weld.

Tensile strength of the weld increases with increases in bead width and because of the higher MIG parameters the wider weld bead, for constant bead hardness isobtained.

FEM simulation is a powerful tool, which has been used to achieve assessments close to the real behavior of the weldings.

Nd : YAG Laser was used in experiments. The power of the laser was kept constant at 4000 Watt. The avg. velocity of the weld was 4 m /min. The weld shield gas was Agron with a flow rate of 25.4 via MIG Pistol. The pulse was 2.5ms filled wired used was OK Autorod 12.51 with 3mm of diameter.

Hybrid Welding combines laser beam welding and arc welding. Separately both types of processes have advantages and disadvantages. The laser beam welding process typically produces a narrow and deep melt profile at high welding speed, but with the drawback of its sensitive to wide joint gaps. The arc welding processes produces shadow and wide welding with low welding speeds. Hybrid welding process combines the advantages of both techniques; hence this is very interesting process in order to improve capabilities, increased welding speed and improve joint mechanical properties. The main drawback of laser hybrid welding is the high number of parameters to control.

Hybrid Welding [Bagger and Olsen 2004] has been studied with respect how the parameters governing the process. Hybrid Welding joints show a pore reduction an a elimination of cracks, as well as it is a useful process to obtain a improvement in ductility and a reduction on hardness with regard to laser welding.

Tensile Shear strength in laser and hybrid welding has also studied [One, Shinbo, Yoshitake and Ohmura 2002]. For constant bead hardness the strength of the weld increases in proportion to the bead width. Hybrid welding provides a wider bead than laser welding, hence, a stronger joint. If base metal strength is higher than weld strength the fracture will be produced on the weld, in the other case the joint will fracture in the base metal.

Spot Welding is a resistance welding method widely used by the industry. This is a welding method fast, cheap and easily of automation. In other hands, spot welding has important draw backs, as the necessity of access from both sides of the joint or the difficulties to know about the quality of the welds.

The strength of a spot welded joint is typically related to its physical attributes as weld button size, nugget and Head Affected Zone size, penetration, indentation, sheet separation and material properties. But, between all of this attributes, only nugget size has been used widely in order to know the relationship between attributes and strength. This is because of there is not a clear knowledge of how them affect the strength of spot welds. Thus, it is very difficult to find a universal relationship between the measurable attributes of a weld and the quality of the weld.

Consequently, these difficulties and its deep penetration in manufacturing processes, like automotive industry, it is necessary to reach a more widely knowledge about modeling of spot welding process.

The objective of the experiments performed was to know the behavior of the joint of a 5mm thickness of Steel 1 with a Steel 2 (4mm thick) in a lap joint with fillet weld.

Join geometry, chose was lap joint, because of its large tolerance of beam position, easy accommodation of materials of different thickness and its ability to weld thin plates. The thicker material, Steel 1, 5 mm thickness, was used in the bottom and thinner sheet, Steel 2 top of it. This also reflects the joint geometry of the component.

During the laser experiments is mainly focus of two of the S1A and S2A. The process data for those specimens are shown in Table.

Laser beam orientation used was 45º.

The experimental work was performed by leading into the stepsas:-

01. LaserProcessing:-

The first day in laser laboratory were spent looking for the right hybrid welding parameters, like position of the torch and laser beam, focal position of laser beam. Once, we found these settings, we carried out the welds.

02. Sample Preparation:-

Once welded, to study the joints, it is necessary to make a metallographic sample preparation. This preparation is consisted of different steps like cutting, mounting, grinding, polishing and etching. These steps have been described more deeply in the introduction.

03. Macro & Micro Examination:

With this step, we want to determinate a high number of defects, as defect or shape of the weld, before & after the failure of weld joint in tension & tensional shearing due to bending.

04. MechanicalTests:-

Welded specimens were divided up into three groups. Hardness Test of weld was performed in first of them and tensile stress test in the second with tensional shear strength due to bending (eccentric) loads in the third one.

05. Analyze the measurement obtained & compared the experimental values with theoretical & simulated testsvalues.

In the following section, we are going to present the results from the properties analysis of three specimens performed with different hybrid welding parameters and a spot resistance weld specimen. Specimen S1A is a sample of low MIG parameters, **32V, 72 A** and a wire feed of **2.5m /min**,whilespecimenS2BisasampleofhighMIGparameters,**38V,216A**andawirefeedof **8 m/min.**

These pictures show a macro section of a hybrid weld joint. Both of these pictures show hybrid laser welding, but each weld were carried out with different parameters.

While specimen S1B shows the typical geometry of a laser hybrid weld bead, in specimen S1A, we can see the lower weld metal, because of its lowers wire feed as **2.5 m/min** Due to low wire feed, we can see several defects, as undercutting and porosity, and an irregular shape in top of the weld.

Both welds have total penetration. It is explained because of the laser determinate the penetration depth. The penetration does not depend on the arc parameters. In both samples, the power of the laser was kept constant, **5000W.**

In the sample S1B, MIG Power is higher, with a voltage of 285V and a current of 206A; hence, its Active Zone is wider. The voltage in the sample S1A is 226V and the current is72A.

It is possible to recognize the Active Zone and the typical nugget (button shape). The size of the nugget is very important of it has been used as the main attribute in relationship with the strength of the weld. Other attributes are not normally used, because it is not clear how they affect the quality and strength of spot welding.

Hardness profile was performed to the middle of the throat of weld, because this profile is approximately symmetric through the other side of thenugget.

Average Vickers Hardness shows values from **425 to 500HV.**

Possibly, HAZ the size of grains become large, this is due to at these points the material has been heated sufficiently long time for grain growth to occur.

The size of the grains in the Heat Affected Zone is smaller in spot welding. The microstructures of the nugget is very similar, but with shorter grains, that the microstructure of the weld bead in hybrid welding. This is caused by the less energy density of spot welding regarding hybrid laser welding.

In Hardness Test

Comparing Hardness Tests of samples S1B and S2B, we can see the hardness values are similar in both of them. The biggest difference may be the wide of the weld bead. In sample S1B is smaller. It can explain that, there is a zone in which exists a difference in hardness between Steel 1 & Steel 2. This difference is because of the points of the graphic show the Heat Affected Zone in Steel 2, while in Steel 1, they show the weldbead.

The minimum hardness value in both hybrid welded samples is approximately the same. There is a weaker point in weld bead of sample. S2B, but the surrounded points have similar values than the othersample.

The lack of weld metal can bring the presence of welding defects, as porosity, but in sample S1B, there is no any weak point in the weld bead.

Vickers profile of spot welding shows the same range of values than hybrid laser welding. There is not a significant difference between the hardness of bothprocesses.

01. Hybrid Laser - MIG Welding has gained significant industrial attention.

02. Various joint configurations can be hybrid welded at high speed, even in the presence of a significantgap.

03. The fundamental physics of hybrid welding has been studied by developing a mathematicalmodel.
04. In contrast to MIG-Welding the torch is inclined, causing a change in energytransfer.
05. Energy transfer is the result of the electrode current, shielding gas convection & Laser BeamAbsorption.
06. The Laser - MIG Welding Process is to be effective then the MIG Parameters must be set high enough to bridge any forecast gap between the work pieces. Practically gaps up to 3mm wererecommended.
07. Comparing hardness tests of samples we see that hardness values are similar in both of them.
08. The use of low values of current, voltage & wire feed induce a small weld bead, increasing the probability of defects in theweld.
09. Tensile strength of weld increase in proportion to the weld bead width, because of the higher MIG Parameters the wider weld head, for construction weld beadhardness.

CONCLUSION & FUTURE SCOPE

- Lack of Agreement in experiment suggests future work based on new design specimens.
- "The influence of joint gap on the strength of hybrid laser - MIGwelds".
- The use of special welding rods to strength partial penetrationwelds.
- The extension of the theoretical model & strength of weld produced with new advanced welding materials &equipments.

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