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EFFECT OF WELDING SPEED ON DEPTH OF PENETRATION, HARDNESS OF HAZ AND LONGITUDINAL DISTORTION OF V-GROOVE BUTT WELD JOINT USING TIG

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ABSTRACT
In this paper study of welding speed and geometry to find out tensile and impact strength in case of butt weld joint will be done. For V-groove geometry different models of plate with various included angles from 30^0, 40^0, 50^0 will be made from structural steel (A633 Grade E). Currently different welding speeds are used in precision welding applications such as nuclear reactor pressure vessels, boilers etc. where welding accuracy as well as quality with strength is an important parameter. So in this paper experimentation will be done on different welding speed such as 0.3 cm/sec, 0.6 cm/sec and 0.9cm/sec to prepare a V-groove butt weld joint. Generally the V-groove geometry with included angle up to 60^0 is in use. After studying the Indian Welding Journal published by Indian Welding Society it is observed that strength of joint is depends upon depth of penetration of filler material and Heat Affected Zone. So this paper concentrate on effect of welding speed on depth of penetration of filler, distortion and HAZ.

KEYWORDS: Welding Speed, TIG Welding, V- Groove Butt Weld Joint, HAZ, depth of penetration, distortion

INTRODUCTION
In current scenario welding has vast application in shipping industry, process industry, in fabrication maintenance, repairs of parts and weld structures. The welding process is used to manufacture a simple steel bracket to the nuclear reactors. There are many methods which are used for metal joining process but welding is one of the fast and convenient methods. The welding is defined as the process of joining method by heating them to their melting temperature and causing the molten metal flow together. Because of vast application of welding in industry there is needed to optimize welding process parameters and to increase reliability, reproducibility and viability. We have to study the different defect such as distortion hot cracking in a systematic and logical approach. Distortion is one of the most widely observed defects in welding process so it is essential to this parameter. The distortion is an unwanted physical change because of welding involves highly localized heating of metal being jointed together. Due to high heating metal are fused together and they will set up non uniform stresses inside the component because of expansion and contraction of the heated material. Initially compressive stresses are created in the surrounding of material due to expansion of the material. The tensile stresses are created due to cooling of the material and contraction of weld metal. So due to uneven cooling and heating some amount of residual stresses are set up in the material.

LITERATURE REVIEW
This section covers the literature review for all welding process and its study carried out by other researchers in the same field. This study can be helpful for improving the weld strength, also reduced in cost of welding. They are summarized below.

R. R. Balasubramanian et.al. (2015) studied and compared the mechanical properties of non-heat treatable aluminum alloy AA5083 and heat treatable Aluminum alloy AA7020 using TIG welding. 5556A filler were used to weld AA7020 alloy and 5183A filler for AA5083 alloy. Effects of pulsing mode over conventional mode of GTA process were also investigated for AA5083 alloy. In this work, gas tungsten arc welding process has been selected because it is low heat input process. Low heat input process has selected because AA7020 and AA5083 were low melting point material. [1]

G. Magudeeswaran et.al (2014) studied quenched and tempered (Q&T) steels are widely used in the construction of military vehicles due to its high strength to weight ratio and high hardness. These steels are prone to hydrogen induced cracking (HIC) in the heat affected zone (HAZ) after welding. The use of austenitic stainless steel (ASS) consumables to weld the above steel was the only available remedy because of higher solubility for hydrogen in austenitic phase. The use of stainless steel consumables for a non-stainless steel base metal is not economical. Hence, alternate consumables for welding Q&T steels and their vulnerability to HIC need to be explored. Recent studies proved that low hydrogen ferritic steel (LHF) consumables can be used to weld Q&T steels, which can give very low hydrogen levels in the weld deposits. [2]

G. Magudeeswaran et. al. (2014) studied the activated TIG (ATIG) welding process mainly focuses on increasing the depth of penetration and the reduction in the width of weld bead has not been paid much attention. The shape of a weld in terms of its width-to-depth ratio known as aspect ratio has a marked influence on its solidification cracking tendency. Hence in this study, the above parameters of a TIG welding for aspect ratio of ASTM/UNS S32205 DSS welds are optimized by using Taguchi orthogonal array (OA) experimental design and other statistical tools such as Analysis of Variance (ANOVA) and Pooled ANOVA techniques. The optimum process parameters are found to be 1 mm electrode gap, 130 mm/min travel speed, 140 A current and 12 V voltage. [3]

Mayur. S et. al. (2013) studied the structural and mechanical properties evaluation of AA-5083 alloy after single pass Tungsten Inert Gas(TIG) welding were investigated to reveal the weld strength, hardness of welded joints by using weld current as varying parameter. AA-5083 alloy plates were joined by TIG welding technique to examine optimal welding current. Welded specimens were investigated using optical microscopy, tensile and Vickers's micro-hardness tests. Optical microscopy was used to characterize transition sites of welded zone, HAZ and base metal. Tensile test was conducted to characterize weld strength by determining ultimate tensile strength and micro-hardness test was conducted to characterize the homogeneity of welding in terms of mechanical properties.. [4]

N. E. Ipek (2012) studied the gas metal arc welding (GMAW) process is extensively used in manufacturing for a variety of ferrous and nonferrous metals because it greatly increases the quality of welding. The objective of this study is to develop an approach that enables the determination of critical GMAW variables and optimization of process variables by using integrated de- sign of experiment (DoE) and goal programming (GP) methods conjunctively. [5]

MATERIALS AND METHODS

In materials and methods detail discussion is carried out, about material used, specimen preparation and welding geometry used.

3.1 Materials

The base materials used for the experimental work is structural steel (ASTM A633 Grade E). This material is commonly used in industry for different application such as refineries, industrial shades, metro station, aircraft hangers, commercial buildings etc. This material has good machinabilty and weld ability. Focus of this project work is to identify the strength of singleV-Groove butt welded joint by increasing the included angle from 30^0 to 50^0. As included angle increases the contact area will also increases, therefore strength also increases. The dimensions of base metal plates are 8x300x300 mm. The composition and mechanical properties of work material ASTM A633 Grade E are given in following Table 3.1, Table 3.2, respectively.

Table -3.1 Chemical Composition of Work Material ASTM A633 Grade E

Elements	C	Mn	P	S	Si	Cr	Cu	Mo	Ni
Weight, max, %	0.23	0.66	0.09	0.016	0.24	1.29	0.40	0.24	2.9

Table -3.2 Mechanical Properties of Work Material ASTM A633 Grade E

Tensile Strength, min, (MPa)	550-690
Elongation, min (%)	18

3.2Preparation of specimen

In literature survey we were investigated in V-groove butt weld joint the volume of filler material required is less so the cost of welding is also less. Also V groove is easy to prepare. So in this experimentation we are going to connect two plates by using V-groove geometry. The selected standard V-groove geometry is as per American Welding Society Handbook.

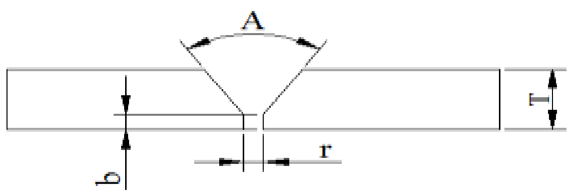


Figure-3.3 Geometry Dimensions as Per Standard of ASTM

Table-3.4 Welding Samples

Sr. No.	Sample Name	Groove Angle (Degree)	Bevel Height B (mm)	Root Opening (mm)	Welding Speed cm/sec
1	D1	30^0	1	2	0.3
2	D2	40^0	1.5	2	0.3
3	D3	50^0	2	2	0.3
4	D4	30^0	1	2	0.6
5	D5	40^0	1.5	2	0.6
6	D6	50^0	2	2	0.6
7	D7	30^0	1	2	0.9
8	D8	40^0	1.5	2	0.9
9	D9	50^0	2	2	0.9

3.3Welding method

Robotic TIG Welding

The OTC AII-V6 is suitable for virtually all MIG, CO2, and TIG welding applications, and air plasma cutting applications. The OTC AII-V6 may be used for common materials such as mild steel, stainless steel, aluminum, titanium, as well as other exotic metals. During TIG welding, an arc is maintained between a tungsten electrode and the work piece in an inert atmosphere (Ar, He, or Ar-He mixture). Depending on the weld preparation and the work-piece thickness, it is possible to work with or without filler. The filler can be introduced manually or half mechanically without current or only half mechanically under current.

RESULTS AND DISCUSSION

4.1 Metallographic Test Results

4.1.1 Metallographic Micro and Macro

A weld area microstructure can provide a wealth of information of weld quality and edge presentation. The sample should be taken with care using a cutting torch. The sample should be large enough that the heat from the cut does not influence the microstructure. The degree of upset, the uniformity of the squeeze, flow angles and micro structural constituents can be determined using standard metallurgical preparation techniques and a metallurgical microscope.

Figure -4.1 Microstructure of Heat Affected Zone (HAZ) At 0.3cm/Sec

Figure - 4.2 Microstructure of Heat Affected Zone (HAZ) At 0.6cm/Sec

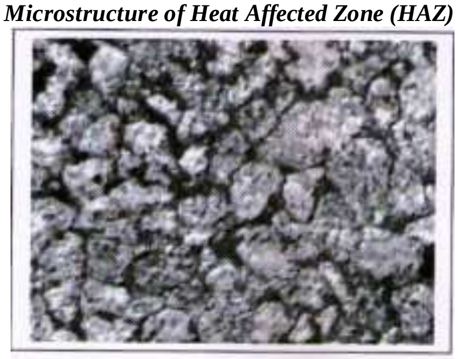


Figure - 4.3 *Microstructure of Heat Affected Zone (HAZ) At 0.9 Cm/Sec*

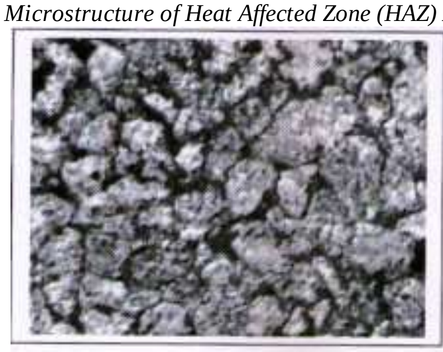


Figure - 4.4 Microstructure of Base Material

- Base metal -The presence of ferrite provides good toughness and tensile strength. It has higher resistance to crack propagation. Fine pearlite is ductile and has good strength. Black spots in base metal reveal that they are fine paralytic region. But as compared to heat affected zone in base metal there are fewer black spots. Hence base metal has good strength as compared to HAZ and weld region.

- Heat affected zone (HAZ) - The presence of temperared martensilte provides good toughness and tensile strength. It has higher resistance to crack propagation. Fine pearlite is ductile and has good strength. Black spots in HAZ reveal that they are fine paralytic region. But as compared to heat affected zone in base metal there are lesser black spots. Hence HAZ has good strength as compared to base metal and weld region.
- Weld area - There is additional presence of dendrite in weld area. By slowly solidifying the molten alloy, it is possible to form a dendritic structure. Dendrites initially grow as primary arms and depending upon the cooling rate, composition and agitation, secondary arms grow outward from the primary arms.
- Macro test or macro examination is performed on the cross section, longitudinal section or 'Z' direction (through thickness) as an independent test to evaluate subsurface conditions or as a subsequent step of another test to reveal the effects on the subsurface.

Figure - 4.5 Macro Test Inspections as Per Standard of ASTM

4.1.2 Discussion on Results

Micro and macro examinations are carried out to check the internal microstructure and defects presents in the welded joints. Initially the sample was welded with speed 0.3cm/sec,0.6 cm/sec and 0.9 cm/sec. The microstructure of HAZ for 0.3cm/sec sample shows fine grains pearlite which is more in quantity as compare to 0.6 and 0.9 cm/sec samples. This is because of more contact of heat source with material due to less speed. These fine pearlite increases the strength but ductility property changes. Micro examination shows there are no defects observed in to the welded joint i.e no cracks, no porosity.

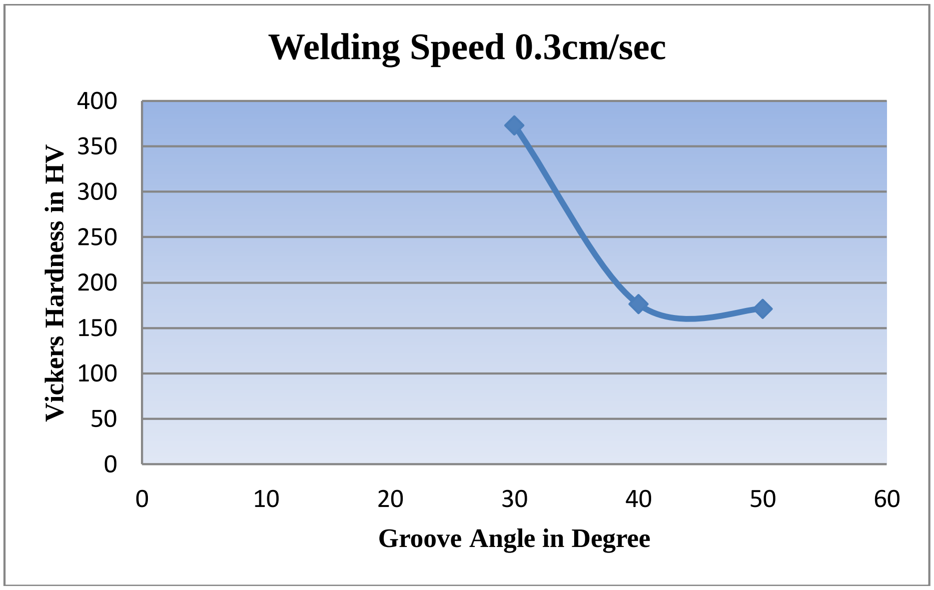
4.2 Vickers Hardness Test Results

Vickers hardness test was conducted in "Urja Laboratories"; the results are in the following form,
Vickers hardness (HV) = Load / Area of indentation

Table - 4.1 Vickers Hardness Results for All Specimens

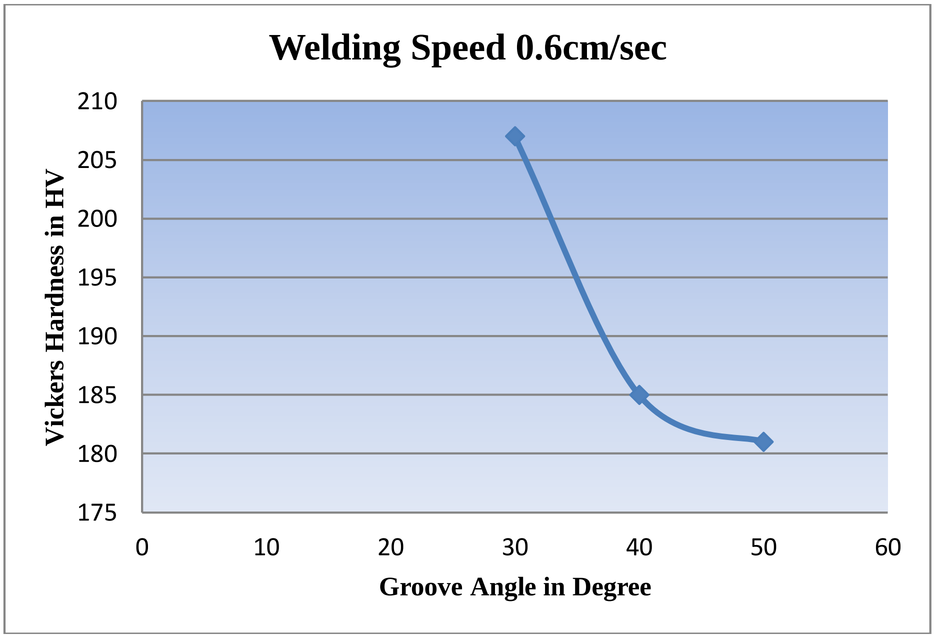
Sr. No.	Sample Name	Groove Angle (Degree)	Bevel Height (mm)	Welding Speed cm/sec	Vickers Hardness HV
1	D1	30^0	1	0.3	373
2	D2	40^0	1.5	0.3	176
3	D3	50^0	2	0.3	171
4	D4	30^0	1	0.6	207
5	D5	40^0	1.5	0.6	185
6	D6	50^0	2	0.6	181
7	D7	30^0	1	0.9	172
8	D8	40^0	1.5	0.9	193
9	D9	50^0	2	0.9	197

4.2.1 Discussion on Results



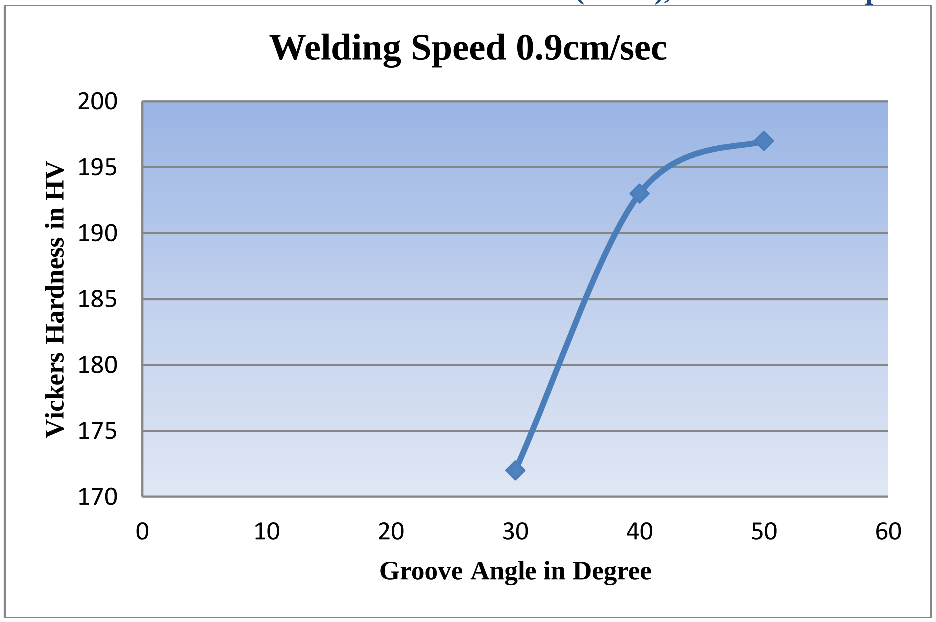
Graph - 4.1 Groove Angle, Welding Speed Vs Hardness of HAZ for 0.3cm/Sec

From experimental data, for groove angle, welding speed Vs Hardness of HAZ graph, it shows that, as the welding speed increases the hardness of HAZ decreases.



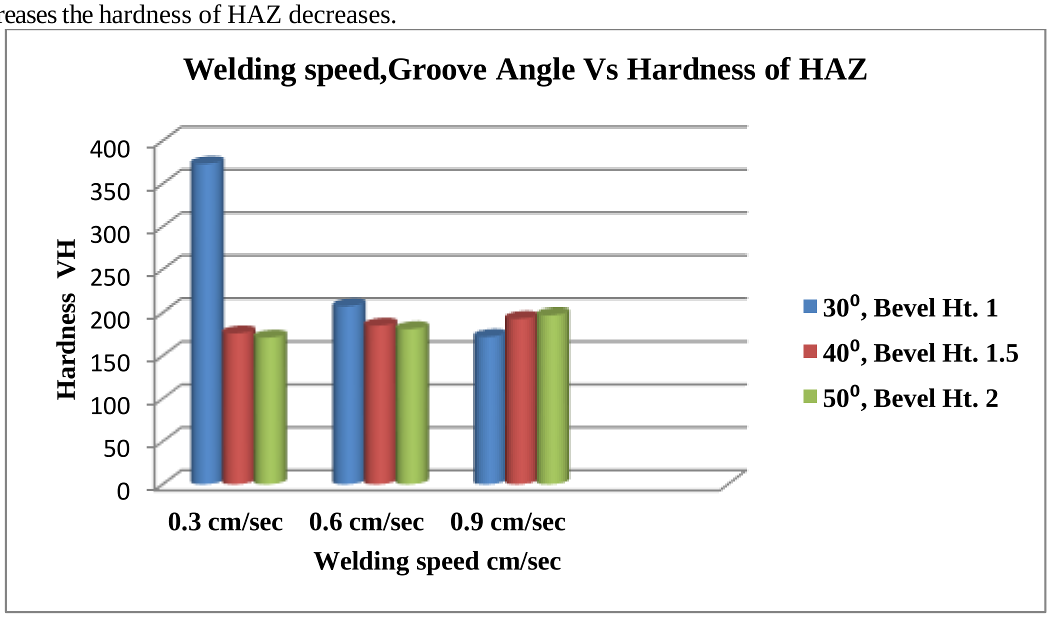
Graph -4.2 Groove Angle, Welding Speed Vs Hardness of HAZ for 0.6cm/Sec

From experimental data, for groove angle, welding speed Vs Hardness of HAZ graph, it shows that, as the welding speed increases the hardness of HAZ decreases.



Graph - 4.3 Groove Angle, Welding Speed Vs Hardness of HAZ for 0.9cm/Sec

From experimental data, for groove angle, welding speed Vs Hardness of HAZ graph, it shows that, as the welding speed increases the hardness of HAZ decreases.



Graph - 4.4 Comparative Results for Hardness of HAZ

As we observed earlier in microstructure examination the HAZ contain fine pearlite in HAZ and due to presence of pearlite the material becomes strong but there is a loss of ductility property. So due to heat the material is subjected to the change in properties. In HAZ material becomes hard as compare to base material. Therefore the ductility property is reduced in HAZ region and material becomes brittle in HAZ. So the possibility of failure in this region increases. So for better strength the welded joint must have less strength.

According to the results the 0.9 cm/sec welding speed shows less hardness as compare to 0.3and 0.6 cm/sec speed. So 0.9 cm/sec welding speed is suitable for less HAZ region.

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4.3 Distortion Result

The results obtained by experimental investigation will be of great useful to the designers to account for the shrinkages taking place during fabrication for the prediction of the degree of shrinkages. The following are the main conclusions are drawn within the scope of the present investigation. The longitudinal shrinkage was increased with increase in the groove angle in single v-groove butt joints.

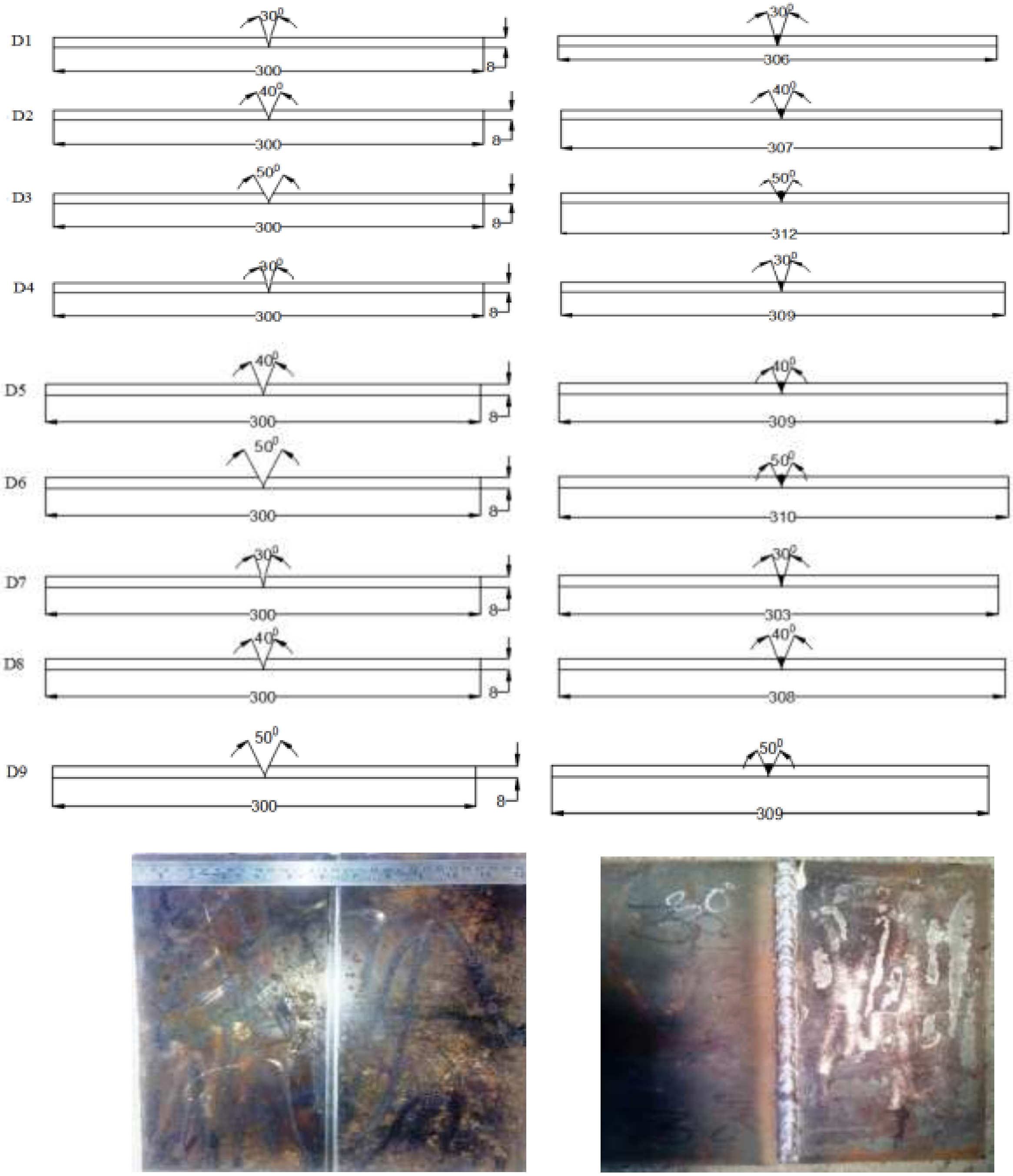
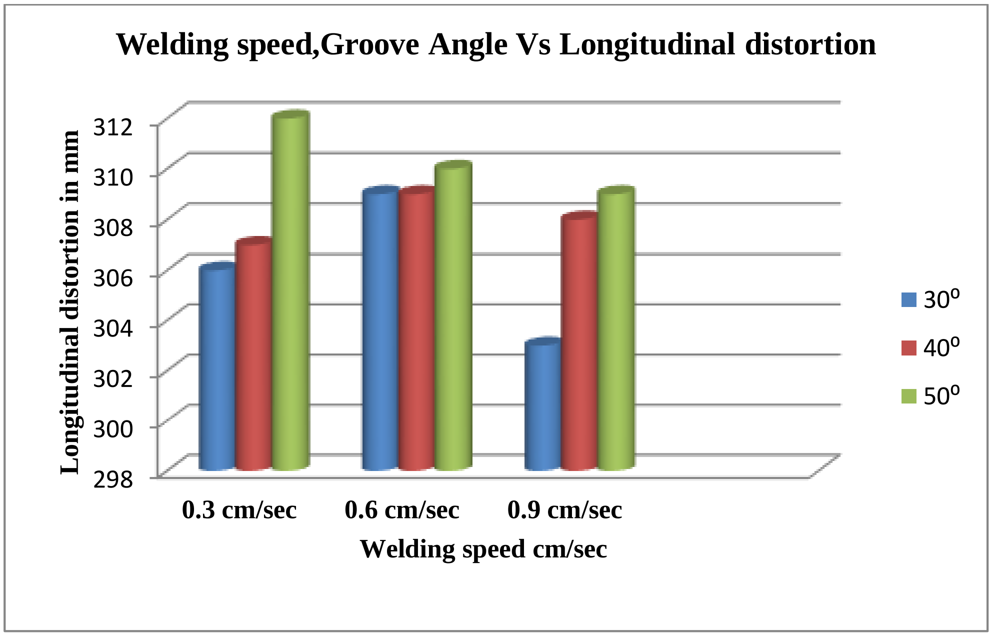


Figure - 4.6 Distortion Specimens Before and After Welding

Table - 4.2 Distortion Results for All Specimens

Sr. No.	Sample Name	Groove Angle (Degree)	Bevel Height (mm)	Welding Speed cm/sec	Longitudinal Distortion	
					Dimension Before Welding mm	Dimension After Welding mm
1	D1	30^0	1	0.3	300	306
2	D2	40^0	1.5	0.3	300	307
3	D3	50^0	2	0.3	300	312
4	D4	30^0	1	0.6	300	309
5	D5	40^0	1.5	0.6	300	309
6	D6	50^0	2	0.6	300	310
7	D7	30^0	1	0.9	300	303
8	D8	40^0	1.5	0.9	300	308
9	D9	50^0	2	0.9	300	309

4.3.1 Discussion on Results



Graph - 4.4 Comparative Results for Longitudinal Distortion

In plate welding there may be possibility of two types of distortion longitudinal and transverse distortion. In this experimentation we concentrate on longitudinal distortion only. The plate has 8mm thickness so the possibility of transverse distortion is less. Distortion is affected by joint design, welding procedure, restrain. The TIG welding has less distortion as compared to other welding processes and at 0.9 cm/sec we are getting less distortion in joint.

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5.4 Depth of Penetration Results

To measure depth of penetration take cut section of welded joint and measure the bead length by scale. Following are the results obtained from samples.

Table - 4.3 Depth of Penetration Results for All Specimens

Sr. No.	Sample Name	Groove Angle (Degree)	Bevel Height (mm)	Welding Speed cm/sec	Depth of penetration mm
1	D1	30^0	1	0.3	8
2	D2	40^0	1.5	0.3	7.2
3	D3	50^0	2	0.3	7.1
4	D4	30^0	1	0.6	6
5	D5	40^0	1.5	0.6	6.1
6	D6	50^0	2	0.6	6.2
7	D7	30^0	1	0.9	6.1
8	D8	40^0	1.5	0.9	6.3
9	D9	50^0	2	0.9	6

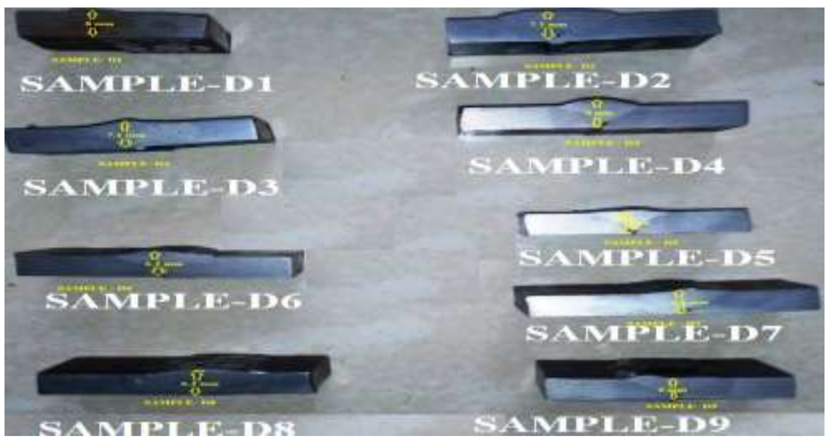

Figure - 4.6 Depth of Penetration Sample after Welding

5.4.1 Discussion on Results

Depth of penetration depends upon different parameters such as polarity, heat inputs, welding process, type of electrodes, travel angle, shielding gas type, electrode diameter, welding speed. In this experimentation we concentrate on welding speed only.

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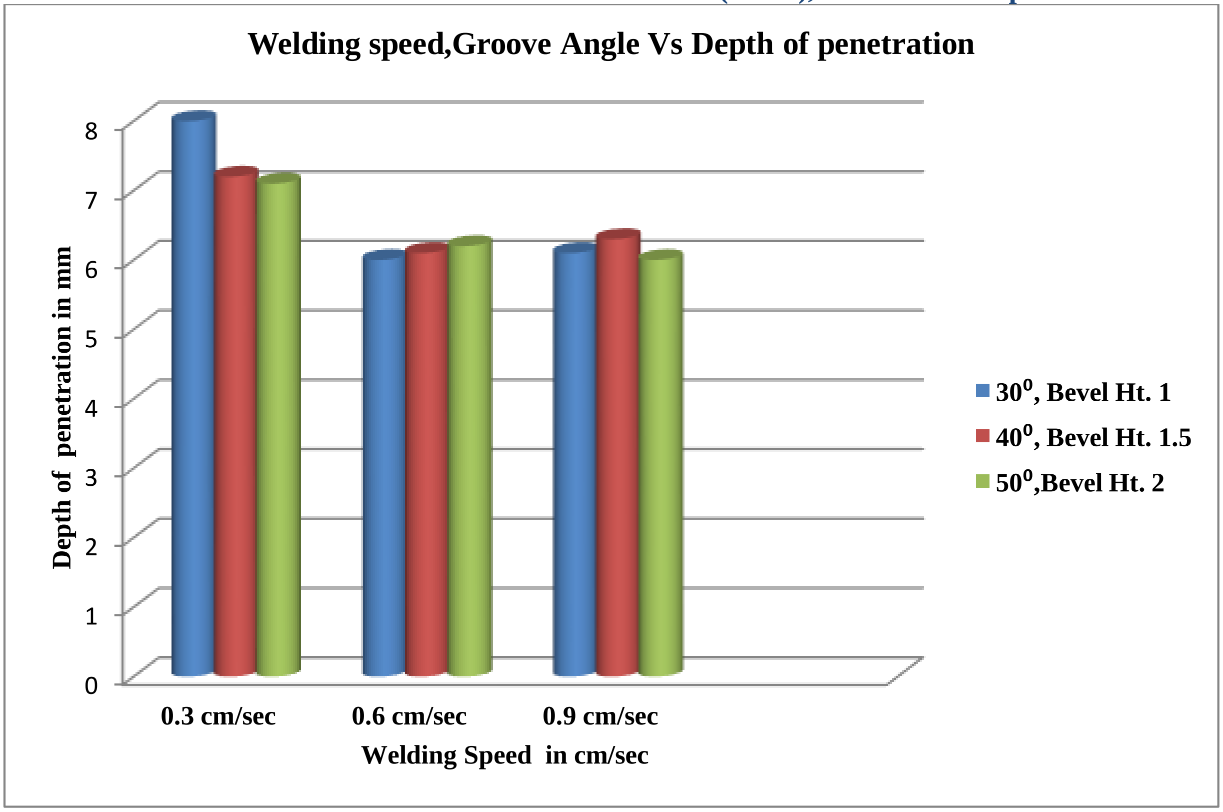

Graph - 4.5 Comparative Results for Depth of Penetration

How fast the electrode travels down the joint affects how much time the arc energy has to transfer into the base plate at any particular point along the joint. As travel speed increases, the amount of time that the arc is over a particular point along the joint is less and the resulting level of penetration decreases. As travel speed decreases, the amount of time that the arc is over a particular point along the joint is greater and the resulting level of penetration increases. So it is observed that at 0.3cm/sec we are getting maximum depth of penetration in butt weld joint.

CONCLUSION

From the results of the present investigation and discussion presented in the paper, the following conclusions are drawn.

1) The longitudinal distortion is less at 0.9 cm/sec welding speed
2) The HAZ is minimum at 0.9cm/sec welding speed. The HAZ is maximum at 0.3 cm/sec welding speed so the hardness and material increases with loss of ductility property in HAZ.
3) The depth of penetration is observed maximum at 0.3 cm/sec welding speed.
4) The strength of butt weld joint increases with increase with groove angle at 40^0 groove angle it is maximum. Also the strength is maximum at 1.5 mm bevel and 0.3 cm/sec welding speed.

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