1-Introduction

Welding is a process in which materials of the same fundamental type or class are brought together and caused to joint through the formation of primary chemical bonds under the combined action of heat and pressure. The tendency for atoms to bond is the fundamental basis for welding. The definition of welding in ISO standard (1958) states; "welding is an operation in which continuity is obtained between parts for assembly, by various means", Robert W. Messler Jr. [1].

Welding offers several advantages but has some disadvantages as well. The significant advantage of welding is undoubtedly that it provides exceptional structural integrity, producing joints with very high efficiencies. The strength of joints that are welded continuously (i.e. full length, without intentional skipped areas) can easily approach or exceed the strength of the base material. On the other hand, the greatest disadvantage of many welding processes is that the requirement for heat in producing many welds can disrupt the base material microstructure and degrade properties. Unbalanced heat input can also lead to distortion, changes in the material and its mechanical properties, and introduction of residual stresses that can be problematic from several standpoints.

Most welding processes rely depends on heat more than on pressure to accomplish joining by creating atomic bonding across the joint interface. Fusion welding processes that employ an electric arc as a heat source are called arc welding processes. More processes use this source than any other source, primarily because heat for fusion can be effectively generated, concentrated, and controlled.

In arc welding processes, energy is transferred from the welding electrode to the base metal by an electrode arc. When the welder starts the arc, both the base metal and the filler metal are melted together to create the weld. This melting is possible because a sufficient amount of power and energy density is supplied to the electrode. As the energy density increases, melting efficiency increases.

The amount of energy available in a heat source is called energy level or energy capacity. Depending on the nature of the energy source, energy level or capacity is measured by watts for an arc welding, through the arc voltage and the arc current as shown in figure (1-1). The transfer of energy from a source to a workpiece is a complex process in which the true energy density of the welding heat source can not be expressed as a précis number. The reason is that it is often difficult to identify and define the area of contact between the heat source and workpiece. Any heat that lost to the surrounding mass of workpieces can and usually does result in adverse effects.

Fig (1-1): Measured volt and ampere during the welding process in the gas metal arc welding (GMAW) machine

Heat input is a relative measure of the energy transferred per unit length of weld. It is an important characteristic because; it influences the cooling rate, which may affect the mechanical properties and metallurgical structure of the weld and the heat-affected zone (HAZ). Heat input can not be measured directly. It can, however, is calculated from the measured values of arc voltage, current and travel speed. As the heat input increases, the rate of cooling decreases for a given base metal thickness. Also, the material thickness, specific heat, density, and thermal conductivity interact to influence the cooling rate. Slow cooling rate, resulting form high heat inputs, can soften the material adjacent to the weld, reducing the load-carrying capacity of the connection.

Heat input limitations are applicable to each weld pass and are not considered cumulatively. They are also applicable only to single-arc welding processes. Multiple-arc processes with the arcs in tandem generally do not provide time for the fist weld bead to cool sufficiently before the trailing arc passes over it and adds additional heat. Varying the heat input typically will affect the material properties in the weld.

The interpass temperature in a multiple-pass weld is the temperature of the weld between weld passes as shown in figure (1-2). The interpass temperature is apt to be raised in order to fill the welding grooves as fast as possible for better welding efficiency, thus for decreasing welding costs. On the other hand, mechanical properties and crack resistibility deteriorate with high interpass temperatures, and in turn, low cooling rates. This is why a maximum interpass temperature often becomes a problem R. Scott Funderburk [2]. Varying the interpass temperature typically will affect the material properties in the weld.

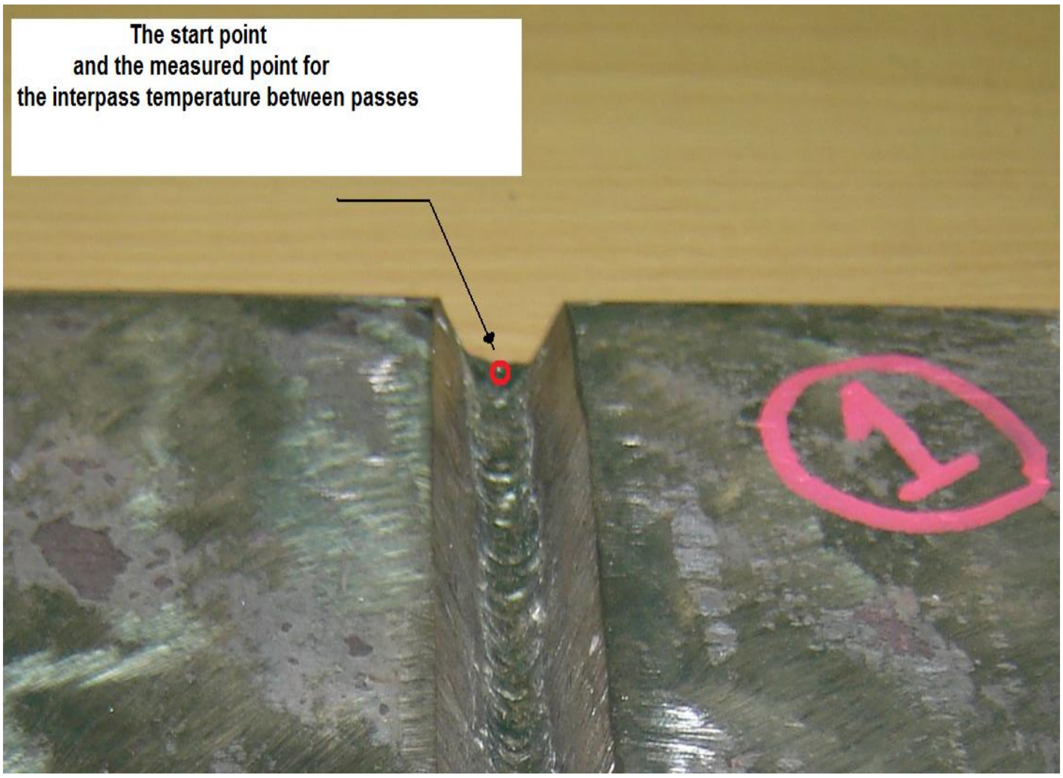

Fig (1-2): The start point in the multipass process and the measured point for the interpass temperature between each pass

One of the things that influence how the heat deposited or generated by an energy source flows and distributes in a weldment is the size and shape of the weldment and, especially, weld joint. The reason joint shape is so important to the flow of heat in a weldment is that the shape determines how much heat must be deposited to fill the joint, where that heat is deposited at the surface or within the joint and whether that heat flow will be three dimensional. In our work, the joint shape is fixed and from the type of complete joint penetration (CJP) single V-groove butt-joint as shown in figure (1-3). The V-groove was made by machining with a certain conditions according to AWS standard code.

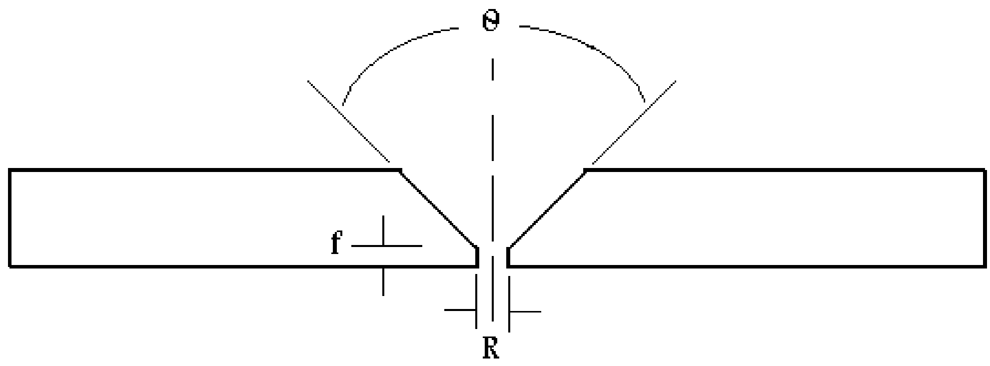

Fig (1-3): Complete joint penetration (CJP) Single-V-Groove butt joint details according to AWS

In considering the effects of heat on melting and solidification in the fusion zone (FZ) and in transformations and reactions in the surrounding heat-affected zone (HAZ) of a fusion weld, it is important to first consider how that heat is distributed once it, reaches the workpiece, that is , how it flows. How that heat is distributed directly influences the rate and extent, of melting, the rate of cooling and solidification in the fusion zone, and the rate and extent of peripheral heating and cooling in the heat-affected zone. The rate of solidification determines the solidification structure and, thus properties.

There is another factor affects on the heat input, which is the welding position. The welding positions are 1G, 2G, 3G, and 4G each one on these item means certain position as shown in figure (1-4). In present work the flat position (1G) and the vertical position (3G) position are used only. Positions are selected to be available with the welding process specially the gas metal arc welding (GMAW). The welding position effects directly on the heat input through the welding power, traveler speed, and the wire feed rate.

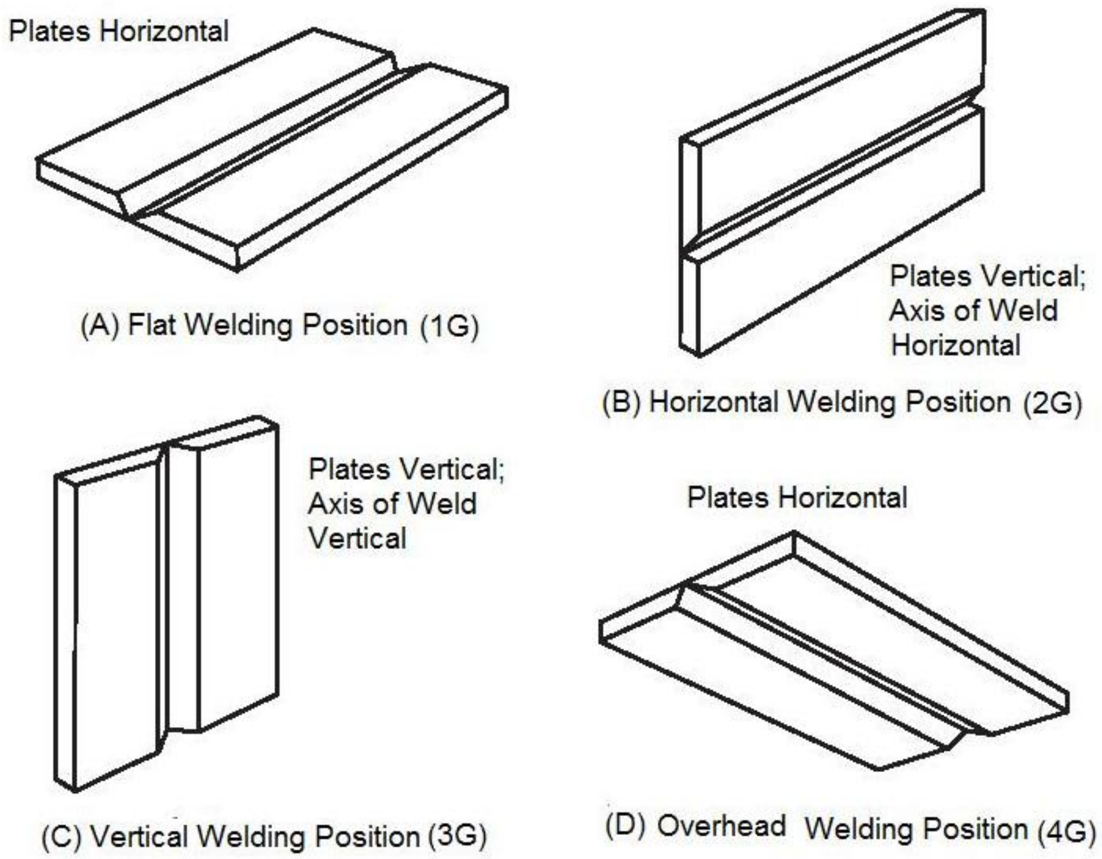

Fig (1-4): Different welding positions for the Single-V-Groove welding process

The second major disadvantage of welding which affects on the mechanical properties of the welded joints is the discontinuities and its location in the fusion zone (FZ) which is not controlled. The discontinuities are imperfections in welds like porosity, incomplete joint penetration, under-cut, under-fill, inclusion, incomplete fusion, and cracks. Ideally, a sound weld should have no discontinuities however, welds are not perfect and imperfections exist in varying degrees.

There is a temptation to call discontinuities defects. The defect is rejectable. Some discontinuities are acceptable. A discontinuity becomes a defect when it exceeds acceptable limits imposed by acceptance standards. The criteria used to distinguish between acceptable imperfections and defects are described in three terms type, size, and location of the discontinuity American Welding Society (AWS) [3].

Porosity is the most commonly discontinuities in welds, especially in gas metal arc welding (GMAW) as shown in figure (1-5). It results when gas is trapped in solidifying metal. The trapped gas comes from either the gas used in the welding process or the gas released from chemical reactions that occurred during the welding process. Porosity usually occurs in the form of rounded discontinuities, but in a severe case the porosity is cylindrical. These large cylindrical pores are referred to as piping porosity. When the porosity aligns and becomes linear, clusters in a particular area, or develops a “tail,” the weld is usually rejectable and detrimental to the weld strength.

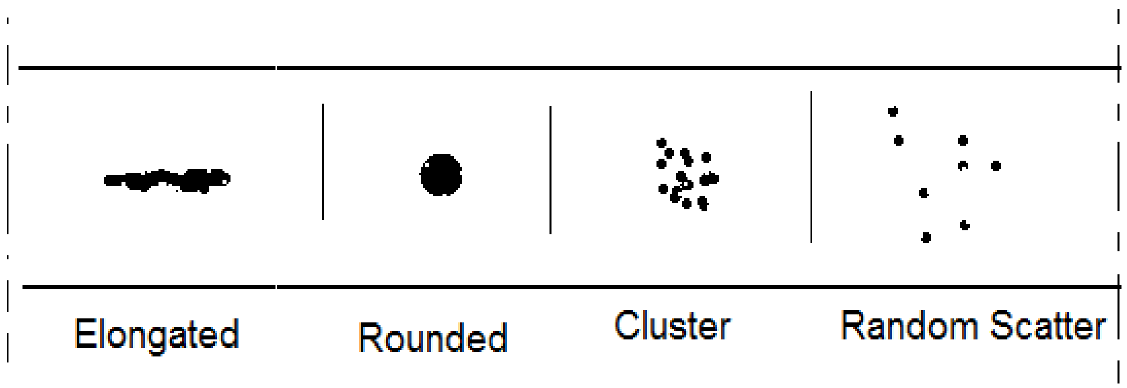

Fig (1-5): Porosity types

In this work the discontinuities will be controlled, by creating an artificial porosity at a certain location and with a certain dimensions in the weld metal within the acceptance criteria (class D) as shown in the table (1-1). And studying the mechanical properties of the welded joints under different welding process variables gives a relationship between the different thermal cycles of the welded joint and the porosity (D) to know the side effect of the porosity class (D) under different heat input.

Discontinuity Severity Class	Discontinuity Specifications
Class **A** Large Discontinuities	This category rejected
Class **B** Medium Discontinuities	This category rejected for a length > 19mm
Class **C** Small Discontinuities	This category rejected for a length > 51mm
Class **D** Minor Discontinuities	This category accepted

Table (1-1): Ultrasonic acceptance –rejection criteria

GMAW method is used in welding at this work. The GMAW process employs a continuous consumable solid wire electrode and an externally supplied inert shielding gas. The wire is fed to the arc by an automatic wire feeder. The externally supplied shielding gas plays dual roles in GMAW; first, it protects the arc and the molten or hot, cooling weld metal from air. Second, it provides desired arc characteristics through its effect on ionization. A distinct advantage of GMAW is that the mode of molten metal transfer and heat input can be changed and controlled through arc current and voltage, and wire feed rate.

In the present work, chapter (1) gives a brief introduction of the welding process variables especially the interpass temperature, welding position, and the heat input. Also, it gives a brief introduction of the discontinuities specially the porosity and its classes according to the AWS and the welding method which is used in the welding process. Chapter (2) gives a critical literature survey for the heat flow and temperature distribution of the welding process, analysis of the previous work and the welding defects. Finally the objective of the present work is also given in chapter (2). Chapter (3) gives the numerical modeling through the mathematical analysis of the governing equations, the boundary conditions, the model analysis in one-dimension and two-dimension, the computational grid, the numerical technique, and the program which is used in numerical solution. Chapter (4) is the experimental work, which shows the welding method, the base metal and electrode specifications, preparation of the welding joints before welding, relieving technique of the residual stresses during welding, temperature measurement techniques in the three-dimension and two-dimension during the welding process, welding variables and their limits, welding joints coding and its conditions which are recorded from the welding machine, welding inspection method to be sure there is no defect in the weld metal after welding, The artificial porosity creation procedure in the welded joint according to the AWS code, welded specimens dimensions according to ASTM code, and finally the error analysis. Chapter (5) gives an experimental design for the experimental results by an empirical equation which helps in the prediction of the tensile strength of the welded joint before welding at any welding variables. Chapter (6) gives the measured and the modeled presentation for the results of the effects of multiple passes GMAW process on the weld thermal cycles, and the 3-D temperature distributions. Also gives, the effects of interpass temperature, welding power, traveler speed, and welding position on the tensile strength, yield strength, elongation percent, surface hardness, and charpy energy for the welded joints free from any defects and containing acceptance artificial porosity class D. A good comparison between the present work and another work is given also. Chapter (7) gives the conclusions that withdrawn from the present work and the recommendations for future works.