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Effects of Inclusions on Microstructure and Properties of Heat-Affected-Zone for HSLA SPFH 590

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Abstract: Micro alloyed steels, often referred to as High-Strength Low-Alloy Steels (HSLA), are a family of materials strengthened by the elements niobium, vanadium and titanium added either singly or in combination While the various compositions of micro alloyed HSLA steels are vital to their unique properties, the processing techniques applied are of paramount importance in achieving maximum potential from a given composition. Strengthening by microalloying dramatically reduces the carbon content which greatly improves weldability and notch toughness The characteristics of inclusions in high strength low-carbon steels have been investigated by using the butt welding thermal simulation, the optical microscopy and scanning electron microscopy. In addition, the effects of inclusions on microstructure and properties of heat-affected-zone were studied.
Keywords: Flash Butt Welding, HSLA Steel, Heat Affected Zone, Microstructure

I. INTRODUCTION

A. The Microstructures and Properties of Base Metals

In the last three decades, micro alloyed. high-strength, low-alloy (HSLA) steels have become established as the materials of choice for a wide variety of structural applications, and they are now viewed by some designers as everyday, garden-variety materials. Carbon steel is fundamentally an alloy of iron and carbon. At room temperature, carbon is virtually insoluble in iron; the maximum solubility of carbon is approximately 0.008 wt%. Below 0.008 wt%, the structure will be made up entirely of ferrite, which has a body-centred cubic lattice, i.e. the lattice is in the form of a cube with one atom of iron at each corner and one at the centre Above 0.008 wt%, any 'excess' carbon combines with iron to form cementite, Fe_3C. Thus, at room temperature, carbon steels consist of a mixture of two phases, cementite and ferrite.

It is important to note that phases in steel should not be confused with structures. Whilst there are many structures or mixtures of structures, there are only three phases involved in any steel; ferrite, cementite and austenite. If the steel is cooled slowly from a temperature above the A3 line, transformation to the body-centred cubic ferrite phase begins when the temperature drops below the A3 line. As the temperature continues to decrease, the transformation is essentially complete once the A1 line is reached. During this transformation, the carbon atoms are expelled from the lattice because they are essentially insoluble in the body-centred cubic ferrite. To all intents and purposes, the steel is returned to the same state it was in before it was heated to form austenite.

II. LITERATURE REVIEW

The impurities are ejected during the plastic deformation caused by the compressive force. A scratching device controls the exceeding material in the welded joint. During solidification, the melting zone of HSLA steels initially transforms into ferrite, and may suffer peritetic reaction with the formation of austenite. This phase, due to the high temperature, experiences a grain growth and tends to show a columnar grain structure. Upon cooling, austenite decomposition occurs at temperatures below 900°C, resulting in distinct phases or constituents. Thus, a variety of microstructures in microalloyed steels are obtained depending on the deformation temperature, cooling rate and the chemical composition.

Fundamental to joining metallurgy are the microstructures of a weld joint, which determine the mechanical properties,and welding variables such as weld thermal cycle, chemical reactions in the molten pool, alloying, flux composition, and contaminants, which significantly affect the weld and heat-affected Metallurgically, a fusion weld consists of three major zones, namely the fusion zone, the unmelted heat affected zone (HAZ) adjacent to the fusion zone, and the unaffected base metal as shown in Fig. In alloys, there also is a fourth region surrounding the weld pool consisting of a partially melted or liquated zone, where the peak temperatures experienced by the weldment fall between the liquidus and the solidus.

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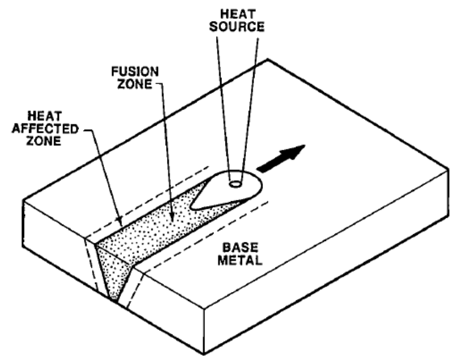


The fusion zone grain structure has a strong influence on the mechanical properties of the weld. To improve both the mechanical behavior and the hot cracking resistance of weld metal, efforts have concentrated on refining the fusion zone grain structure The weld pool shape also influences the fusion zone grain structure. For example, in an elliptically or circularly shaped weld puddle, not only does the magnitude of the maximum thermal gradient change continuously from the fusion line to the weld centerline but also the direction of this gradient changes.

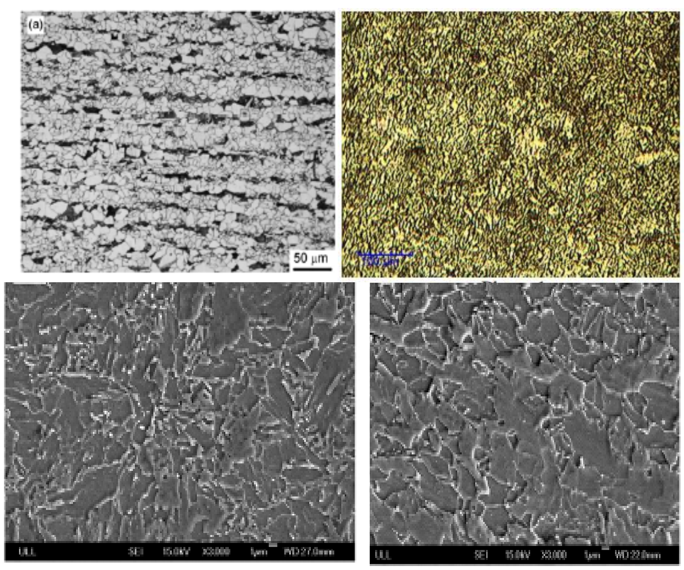
Weld-metal grain structure is predominantly controlled by the base-metal grain structure and the welding conditions. Initial growth occurs epitaxial at the partially melted grains. Both growth crystallography and thermal conditions can strongly influence the development of grain structure in the weld metal by favoring a strong grain-growth selection process. Growth crystallography will influence grain growth by favoring growth along the easy growth direction

A. Experimental Works

Microalloyed steels, often referred to as High-Strength Low-Alloy Steels (HSLA), are a family of materials strengthened by the elements niobium, vanadium and titanium added either singly or in combination. The micro alloying elements are used along with other strengtheners such as boron, molybdenum, chromium, nickel and copper and their use is accompanied by strict control of impurities such as sulphur, oxygen, nitrogen and phosphorus. Strengthening by micro alloying dramatically reduces the carbon content which greatly improves weldability and notch toughness.

B. The Characteristics Of Inclusions

Figure shows the OM images of inclusions in the experimentalsteels. From the OM images of polished cross- sections,the inclusions seem to be almost spherical. The inclusionsin the two steels both distribute homogeneously andthere is no obvious congregation. Moreover, the area densityof inclusions in steel No. 2 is higher than that in steel No.1. There is a larger proportion of TiO*x*/MnS complex inclusions in steel No. 2.



Reduced carbon content has been necessitated to improve a variety of properties, varying from plate weldability and fracture energy to formability in sheet steels.

Phosphorus reduction improves properties such as crack tip opening displacements in the heat-affected zones of plate weldments.Removal of Sulphur from steel is of generic benefit to all HSLA steel products, except in specialized bar products where sulphur improves machinability. The harmful gases hydrogen, oxygen and nitrogen have been progressively reduced in modern HSLA steels, with few exceptions.

Unlike the use of carbon and manganese, the use of microalloying to improve the strength and toughness of HSLA steels did not come about by accident. On the contrary, it was the result of purposeful and methodical research. It was discovered that using niobium (200- 400 ppm) was a way of usurping, in large part, the strengthening role of carbon.

Microalloying with 1,000 ppm vanadium, however, was found to be more a way of exploiting the carbon (and nitrogen) accidentally present in steel. Similarly, microalloying with titanium (0.50-200 ppm) was found to be a way of almost entirely eliminating the effects of accident a l nitrogen, because of the very powerful high-temperature affinity between these two elements. A combined addition of vanadium and titanium, vanadium and niobium, or niobium only, provides for this increased grain refinement and, hence, improved toughness.

III. RESULTS AND DISCUSSION

A. *Influences of Deoxidizing Methods on the Characteristics of Inclusions*

It can be concluded from the results above that the type, number and size of inclusions in the experimental steelswith different deoxidizing methods are different. Different inclusions play different roles in phase transformation in HAZ, so the two kinds of steels consisted of different microstructures after welding thermal cycles.

The equilibrium precipitation temperature of Ti oxide was about 1670°C.

Then TiN and MnS inclusions began to precipitatein the steel at the equilibrium precipitation temperature of approximate 1400°C. In contrast, $_{AO3}$ inclusion precipitated preferentially in steel No.

1 and its equilibrium precipitation temperature was 1740°C or so. Subsequently,TiN and MnS inclusions precipitated at the temperature of approximate 1420°C.

It can be judged that TiO*x* and Al_2O_3 inclusions form in the liquid state and TiN and MnS inclusions form during solidification. The equilibrium precipitation temperature of $A1_2O_3$ is higher than that of TiO*x*. The equilibrium precipitation temperature of TiN and MnS inclusions in Al killed steel is also higher than that in Ti killed steel.

Titanium is a kind of active element in the liquid state.Once it is added to the liquid steel, Ti-containing inclusionswill form immediately. In the process of solidification, theseinclusions can be effective nucleation cores.

The MnS inclusions precipitate at the surface of TiO*x* in the lower temperature,which reduces the growth tendency of MnS inclusions. That is why there were many TiO*x*/MnS complex inclusions in steel No. 2.

B. *Influence of Microstructures on Properties of HAZ*

The impact energy of steel No. 2 was 140Jwithdifferent welding cycles is higher than that of steel No. 1.of 115J This is attributed to the different microstructures of the experimental steels after welding thermal simulation. It can also be judged that the $A1\ _2O\ _3$, TiN and MnS inclusions cannot promote the formation of IAF. The microstructures of steel No. 1 are mainly bainite and polygonal ferrite.

As studied above, there are many TiO*x*/MnS complex inclusions in steel No. 2. Since the dispersing TiO*x*/MnS inclusions act as heterogeneous nucleation sites, they can promote the formation of acicular ferrite. The needle-like acicular ferrite laths are arranged in an interlock manner, thus sectioning a large austenite grain into many small grain colonies.

The formation of bainite at lower temperatures isconfined in the smaller regions, resulting in finer bainite which is much smaller than the prior austenite grains. On the other hand, the acicular ferrite has a high angle boundary and a high is location density, which can induce a larger strain in steels. Thus, the acicular ferrite can retard the rapid propagation of crack, improve the strength and impact toughness effectively, and reach the best match of strength and toughness. Therefore, acicular ferrite can improve the weldability of HAZ.

It can also be seen that the size of austenitic grain grows larger and larger as the cooling time extends further. These factors may deteriorate the properties of heat-affected-zone.

Finally, the deteriorative effects of structures coarsening and the optimized effects of IAF have a comprehensive influence on the properties of the experimental steels, ferrite plays an important role in the refinement of austenite grain and microstructure.

IV. CONCLUSIONS

A. The inclusions in Al killed steel with Ti addition are mainly $A1_2O_3$, MnS and TiN. The inclusions in Ti killedsteel with the oxide metallurgy technology are mainly TiO*x*/MnS complex inclusion and single MnS. The TiO*x*/MnScomplex inclusions with the size in 1-3µm can promote the formation of intragranular acicular ferrite.

B. The microstructures of Al killed steel with Ti addition consist of parallel arrangements of bainite laths and polygonal ferrite. In contrast, the microstructures of Ti killed steel with the oxide metallurgy technology feature intragranular acicular ferrite because of the presence of effective nucleation sites. The impact energies of the latter in different welding thermal simulation conditions are higher than that of the former.

C. Even if the grain ferrite forms preferentially, plenty of intragranular acicular ferrite can still nucleate at complex inclusions in Ti-killing steel with the oxide metallurgy technology. The interlock nature of IAF provides fine effective grain size and fine microstructure, thereby increasing HAZ toughness.

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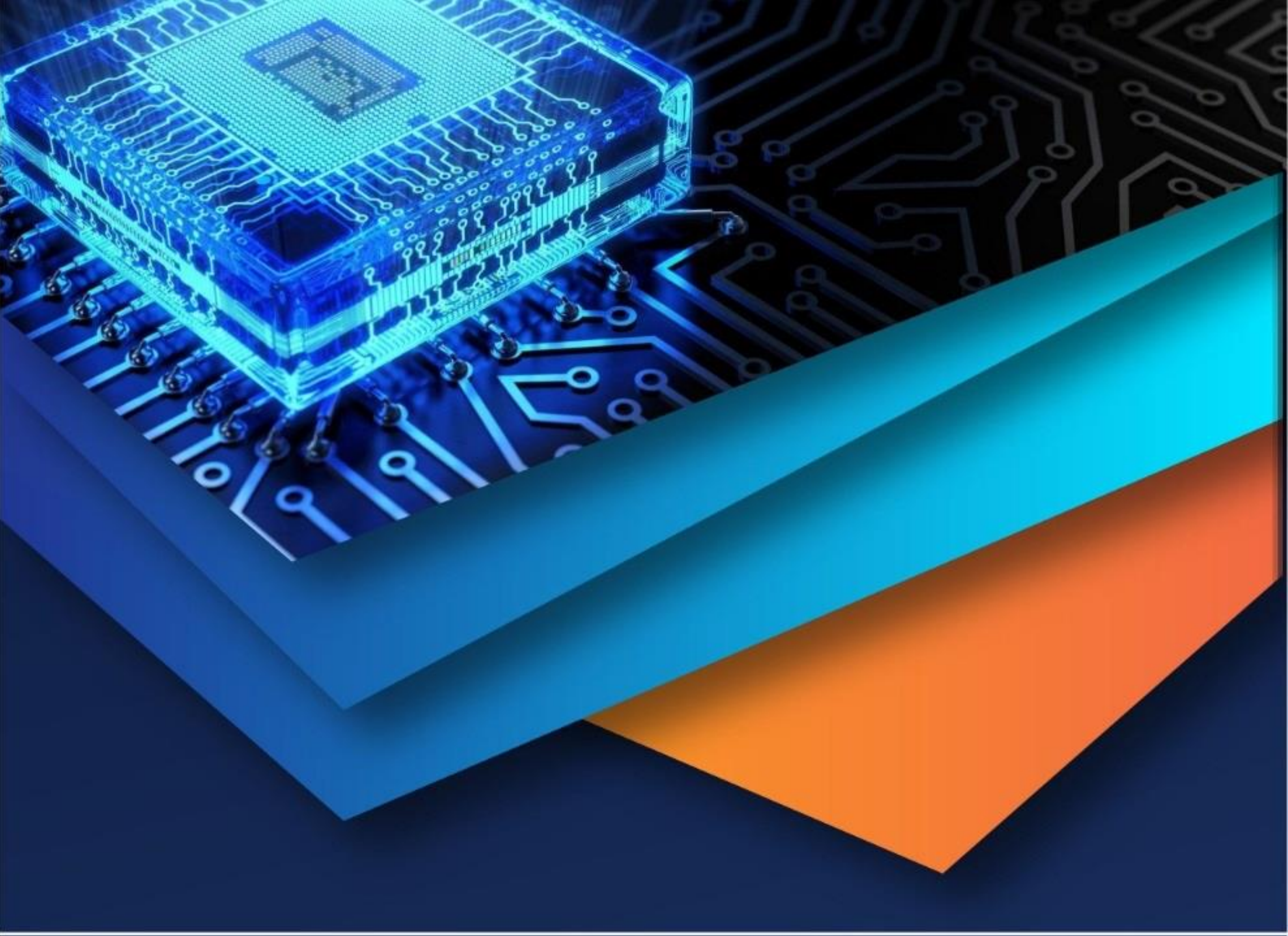

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