Waste Reduction and Environmental Protection through Recycling of Submerged Arc Welding Slag

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ABSTRACT

Global emphasis on waste reduction and conservation of natural resources has lead the scientists and engineers to find out innovative methods of reducing and recycling the industrial waste. Slag generated in Submerged Arc Welding (SAW) is one of such wastes which is produced in very large quantity. Being non-biodegradable it does not decay with time thereby causing environmental pollution. Its dumping leads to wastage of precious natural resources which are its constituents. All these problems can be minimized by developing suitable technologies for the recycling of SAW slag. This paper briefly discusses the state of art of the recycling and reuse of SAW slag.

Keywords: Submerged Arc Welding (SAW), Slag, Industrial Waste, Recycling, Reuse.

1. INTRODUCTION

Submerged arc welding (SAW) is a high productivity welding process which was invented in 1930 [1]. Due to its inherent qualities like high metal deposition rate, fast travel speed, absence of splashes and spatters, high repeatability and ease of automation, the process was readily accepted by the industry. By mid fifties it became an inevitable tool for the welding of pressure vessels, boilers, heat exchangers and other such applications [2]. At present the process finds wide industrial application due to its easy of applicability, high current density and ability to deposit a large amount of weld metal using more than one wire at the same time [3]. It has been estimated that about 7-10% of weld metal deposited all over the world is by the SAW process [4]. The process finds applications in a wide variety of industrial operations such as welding of similar and dissimilar metals, cladding, hardfacing and rebuilt of worn out parts.

The SAW process make use of loose granular flux, which is poured on to the job just ahead of the arc [1]. The flux serves many purposes such as protection of the weld pool from the environment, refinement of the molten metal, transferring alloying elements from and into the weld pool and controlling the shape and size of the weld bead. In general, the flux is an essential constituent of the SAW process. SAW flux gets converted into slag during the welding process and is discarded as waste. As the slag is non biodegradable in nature, it’s dumping causes environmental pollution. It also causes wastage of natural resources which are constituents of the flux [4]. The scientists and researchers had been striving hard to find a solution to the problem of proper disposal of the SAW slag [5]. In general, the problems associated with the SAW slag can be solved only if some suitable method is found to recycle and reuse the slag as flux in the same process repeatedly.

This paper briefly discusses various possible strategies for recycling and reuse of the submerged arc welding slag with the aim of waste reduction, environmental protection and the conservation of natural resources.

2. REUSE THE SUBMERGED ARC WELDING SLAG

Some scientists and researchers explored the possibility of disposing of the submerged arc welding waste by using it in building construction. The possibilities of using the crushed and pulverized slag by mixing it in the sand for making multiple-use mortars and ceramic bricks have been explored. The work done by Viana et. al. [6] showed that the mortar made by mixing upto 20% pulverized slag can be safely used in construction of buildings. Similarly, it was shown that the clay bricks made by mixing upto 10% of pulverized slag posses the same strength and other desired properties as are needed in building construction. Morete et. al. [7] also performed experiments to investigate the possibility of using the welding slag in the manufacturing of red ceramic. They also investigated the effect of addition of different quantities of welding slag residue in different firing conditions. It showed that the SAW slag could be used as an alternative raw material for the clay mass to be used in the manufacture of red ceramic. The physical-mechanical properties of technological interest of the red ceramic bodies show only a small variation with the incorporation of up to 10% by weight of the SAW slag residue. These studies have established that the SAW slag can be used by mixing it with the building construction materials without affecting the quality of construction. Although, using the slag in this manner can solve the problem of disposing the industrial waste to some extent, but it will not solve the problem of wastage of natural resources like minerals which are the constituents of the flux.

Some researchers also explored the possibility of reusing slag as flux in the same welding process in which it was produced [8, 9]. The slag was crushed and sieved so as to it make its particle size distribution similar to the original flux. The crushed mass thus obtained was used as flux in the same welding process again without any further refinement. The resulting weld pieces obtained by using the crushed slag were tested for their visual appearance, chemical composition, strength, microstructure and micro hardness. The comparison of results showed that the chemistry of the weld metal deposited with the crushed slag was not within the AWS specifications. The visual appearance was poor and the other properties were not upto the mark [9]. It established that the crushed slag cannot be used as a substitute of the fresh flux without any further processing.

Efforts were made by some researchers to examine the possibility of using a mixture of fresh flux and crushed slag as a substitute of fresh flux in SAW welding. Moi et al. [10] and Dutta et al. [11] performed scientific studies in this regards. The main and interactive effect of using slag-mix and the process parameters on features of bead geometry and heat affected zone (HAZ) such as bead height, depth of penetration, bead width and HAZ width was evaluated through analysis of variance (ANOVA) method. This study was extended by Pal et al. [12] who tried to find out the extent of acceptability of using slag-mix in conventional SAW processes without sacrificing any characteristic features of weld bead geometry and HAZ within the experimental domain. The study revealed that upto 20% of slag-mix should be used without affecting the quality of the resulting welds. However, using these methods only upto 20% of the SAW slag could be reused and the remaining 80% of the slag will still have to be discarded as waste. Therefore this method does not offer a complete solution to the problem of disposal of SAW slag.

3. COMPLETE RECYCLING OF SLAG

None of the methods discussed in the previous subsection offers a complete solution to the problem of recycling of SAW slag. This problem can be completely solved only by developing some method whereby the entire slag generated in the process can be suitable processed and recycled to flux in a closed loop manner.

Various scientists and researchers have made attempts to achieve this aim, in the past. The very first trial to recycle the slag was made by Alfred Beck in 1959 [13]. He use a closed loop recycling process and started recycling the SAW slag by 1963. But due to stringent AWS and ASME codes prevailing at that time, which did not permit the recycling of slag, the response to this recycling from the industry was negative. The AWS and ASME codes were amended to permit the use of recycled flux by 1996. Eagar [13] investigated on reprocessing and reuse of the fused slag as means of reducing costs of submerged arc welding of titanium. Beck and Jackson [14] found that if it is processed properly and according to code requirements, recycled slag can be reliably used as an alternative to fresh flux. Devis and Baily [15] found that fused calcium silicate flux, which has fully reacted during manufacturing, produces no change on reheating. Harbert Inc. & TITUS Steel Company in USA has been reclaiming slag for fabricators in the USA. However due to commercial interests they have not made the technology public.

Singh et al. [16] investigated to see the effect of recycled slag on bead geometry in submerged arc welding. The slag was processed by replenishing with suitable alloying elements/deoxidizers and then converted into new flux called recycled flux. Recycled flux was used to study the effect of welding parameters on bead geometry and shape relationships. Mathematical models were developed using a two level half factorial technique to predict weld bead geometry and shape relationships. As a continuation of their study, Sing et al. [4] further observed that the chemistry of weld metal was within the acceptable range of AWS specifications. Singh and Pandey also studied the mechanical properties [4] of the weld metal obtained using recycled slag & found it to be in accordance with the AWS code requirement.

Garg et al. [5] developed a technology for complete recycling of SAW slag generated during cladding of stainless steel. The authors carried out a complete investigation on the chemistry, bead geometry, corrosion resistance, microstructure and micro hardness of the metal cladded using the recycled slag and found all the qualities to be well within the acceptable range and quite comparable to the metal cladded using the equivalent fresh flux. At the same time the cost of the recycled slag was found to be only 23% of the original flux.

4. CONCLUSION

Slag is an inevitable by-product of the submerged arc welding process which is produced in a large quantity. Recycling and reuse of the flux is important for the environmental protection and conservation of natural resources. Over the time scientists and researchers have tried to explore various methods for disposal and reuse of SAW slag, but none of these methods offer a complete solution to the problem. Complete recycling of slag has emerged out be a solution which offers the benefits of environmental protection, resource conservation and cost reduction at the same time.

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