APPLICATION ENGINEERING REPORT

FROM

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Statement Regarding the Use of Crushed Slag as Welding Flux

POSITION: Lincoln Electric does not recommend or support the use of crushed slag generated from welding with virgin flux as it will often bear little similarity to the original flux.

Terms and Definitions

- ***Welding Flux,*** *submerged arc welding.* A granular material comprised of metallic and nonmetallic constituents applied during welding to provide atmospheric shielding and cleaning of the molten weld metal. This material may also provide filler metal and affect the weld metal composition.

- ***Virgin Flux,*** *submerged arc welding.* Unused flux produced using new raw materials.

- ***Slag.*** A nonmetallic product resulting from the mutual dissolution of flux and nonmetallic impurities in some welding and brazing processes.

  From AWS A3.0M/A3.0:2010

- ***Crushed Slag***. Slag formed during the welding process that is subsequently crushed for use as a welding flux is defined as crushed slag.

- ***Closed-Loop Crushed Slag***. Slag generated by a fabricator from a specific brand of flux under controlled welding conditions and crushed for subsequent reuse by the same fabricator is defined as closed-loop crushed slag.

  From AWS A5.23: 2007/AWS A5.17:1997

General discussion: Slag processing companies offer services that crush or grind the slag generated during welding for use as a welding flux. This crushed slag may be sized and mixed with virgin flux prior to use as a welding flux. Manufacturers who utilize these services should be aware of the differences that exist between crushed slag and the corresponding virgin flux and how those differences affect weld performance.

General Overview: Ingredients for use in welding fluxes are very carefully chosen to provide specific benefits to the submerged arc welding process, including cleansing the weld metal, providing appropriate weld metal composition (carbon, manganese, silicon, oxygen, nitrogen, etc.), protecting the weld puddle from atmospheric contamination, stabilizing the arc, allowing for ease of slag removal from the weld metal, and providing the appropriate slag viscosity and freezing range for intended applications. When virgin flux is melted by a welding arc, it does not fully reach an equilibrium state. Although the specific elements contained in the slag may be similar, the chemical form of these elements in the generated slag will be significantly different from that of the virgin flux.

The Form of the Elements: One of the most important functions of welding flux is cleansing the weld metal, including oxides and sulfides that would otherwise be dissolved in weld metal, or would be present in the form of inclusions. Fluxing agents must be in the correct chemical form to achieve the intended reactions in the weld metal. After these reactions occur, the slag will have different chemical forms than the original virgin flux.

For example, manganese and manganese oxide in virgin flux often transform into manganese silicates in the slag. All of these compounds will appear as Mn when analyzed by the most commonly used chemical analysis method, x-ray fluorescence. However, each of these forms of Mn will provide very different levels of cleaning and alloying to the weld metal. In addition, each has different melting characteristics which will influence the operability of the flux.

Impurities in Slag: In the welding process, melted flux mixes with molten weld metal to form chemical compounds that pull impurities out of the weld and into the slag. When slag is crushed for subsequent reuse, the compounds needed to cleanse the weld are already bonded to impurities and unable to perform this function. Crushed slag is intrinsically higher in these harmful impurities, like sulfur, carbon, and silicon, since the virgin flux removes these from the weld metal and adds them to the slag.

Contaminants such as copper come from the welding wire, contact tips, or even ground cables. There is no practical way to separate these small pieces of copper from the slag. When present in crushed slag used for welding may cause weld cracking.

Operability and Appearance: Virgin flux and its crushed slag generally have significantly different melting points. This is due to changes which occur in the form of the oxides, silicides, fluorides, metals, etc. Further, materials that are included in virgin flux to stabilize and shield the arc during welding are no longer available in the same chemical form as originally intended after melting. Change in the compounds upon melting will often detrimentally affect the welding performance of crushed slag such as, slag removal and operability, potentially resulting in lower travel speeds and productivity.

Physical Properties of the Slag: Blending crushed slag with virgin flux is a common practice by flux processors. Crushed slag is approximately 20% more dense than the virgin flux it was generated from. This will promote segregation of any blends of crushed slag with virgin flux. It can also significantly increase the consumption of welding flux and increase the slag to metal ratio.

Flux Density and Consumption: Grinding of slag produces a large amount of fine particles which affects flux particle distribution and density. Differences in flux density can negatively impact weld bead wetting, arc stability, slag removal and weld appearance. Crushed slag is denser than virgin flux and will segregate from virgin flux in crushed slag blends. Table 1 shows the increase in density and flux consumption when welding with crushed slag blends with increasing percentages of crushed slag.

Table 1

FLUX DENSITY AND CONSUMPTION TEST RESULTS		
Amount of Crushed Slag in Blend	**Flux Density (g/mL)**	**Increase in Flux Consumption[1]**
0%	1.45	—
40%	1.44	4.7%
50%	1.53	9.3%
60%	1.54	15.1%
100%	1.72	17.4%

[1] When compared to 100% virgin flux.

Closed-Loop Crushed Slag: Slag generated by a fabricator from a specific brand of virgin flux and crushed for subsequent reuse by the same fabricator is referred to as closed-loop crushed slag. It is important to note that the differences between virgin flux and crushed slag are no different for closed-loop crushed slag.

Chemical Analysis and Mechanical Properties of the Weld: The different cleansing and alloying that crushed slag imparts versus virgin flux can affect the mechanical properties of the weld metal. Several examples using agglomerated virgin fluxes and the crushed slag generated from these fluxes are shown in Table 2 below. The most consistent difference is the significant decrease in tensile and yield strength when using crushed slag as a welding flux. This is a result of the substantial decrease in %Mn and %Si in the weld deposit. The Charpy Impact toughness varies and may be higher, lower or the same when welding with the crushed slag. This is largely dependent upon the change in the alloy level, impurities in the weld metal, and the number and size of the inclusions.

Table 2

MECHANICAL PROPERTIES - Virgin Flux vs. Crushed Slag										
Flux or Crushed Slag Welded with EL12 Electrode	**Tensile Strength**		**Yield Strength**		**%Mn**		**%Si**		**Charpy V-Notch**	
	ksi	**% Change**	**ksi**	**% Change**	**% of Total**	**% Change**	**% of Total**	**% Change**	**ft•lbf @ °F**	**% Change**
Flux #1										
Virgin Flux	74	-9.5%	63	-6.3%	1.30	-28.5%	0.52	-44.2%	46 @ -20°	47.8%
Crushed Slag	67		59		0.93		0.29		68 @ -20°	
Flux #2										
Virgin Flux	77	-11.7%	68	-11.8%	1.30	-28.5%	0.50	-58%	67 @ 0°	-59.7%
Crushed Slag	68		60		0.93		0.21		27 @ 0°	
Flux #3										
Virgin Flux	78	-10.3%	69	-13.0%	1.20	-26.7%	0.53	-49.1%	44 @ 0°	40.9%
Crushed Slag	70		59		0.88		0.27		62 @ 0°	

AWS Classification for Crushed Slag: The AWS A5.23 and A5.17 specifications have requirements regarding the classification and packaging of crushed slag, or blends of crushed slag with virgin flux. The trade designations or trademarks of crushed slag or blends of crushed slag with virgin flux must clearly differentiate it from the original virgin flux used in its manufacture. Slag processing companies are required to verify if the blend of crushed slag with virgin flux is in full conformance with the classification requirements of the AWS A5.23 and A5.17 specifications. AWS A5.17 and A5.23 also

require that “crushed slag or a blend of crushed slag with virgin flux shall have a unique trade designation that clearly differentiates it from the original virgin flux used in its manufacture.”

Conclusion: Using crushed slag blends in the submerged arc welding process is ultimately the decision of each individual manufacturer. Flux processing companies promote crushed slag blends as a way to reduce the cost of welding consumables. Before switching from virgin flux consider the consequences to welding performance presented in this article. The deterioration of welding performance that compounds with each cycle of regrind reduces the maximum capacity of each welding station and adds variables that adversely affect welding quality. The use of crushed slag is closely regulated by welding codes, due to its inherent variability and is not supported nor recommended by virgin flux manufacturers. For more information, please contact your local Lincoln Electric Sales Representative.