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DEVELOPMENT OF CERAMIC-COATED WELD BACKING BARS

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DEVELOPMENT OF CERAMIC-COATED WELD BACKING BARS

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INTRODUCTION

In shipbuilding and many other industries, copper weld backing bars are used to draw the heat out of the weld (see Fig. 1). The problem that some users of these bars encounter is that these bars, on occasion, actually melt in spots and become welded to the weld plates. After this happens a number of times, the backing bar becomes so degraded that it must be either discarded or machined, both of which are very costly and time-consuming actions. To avoid this fusion between the backing bar and the weld plate, the weld processes that are used cannot be ones of high heat input. This requirement is very limiting when thick plates are being welded. The plates must be beveled, and more weld passes must be run. These problems are also costly and time consuming.

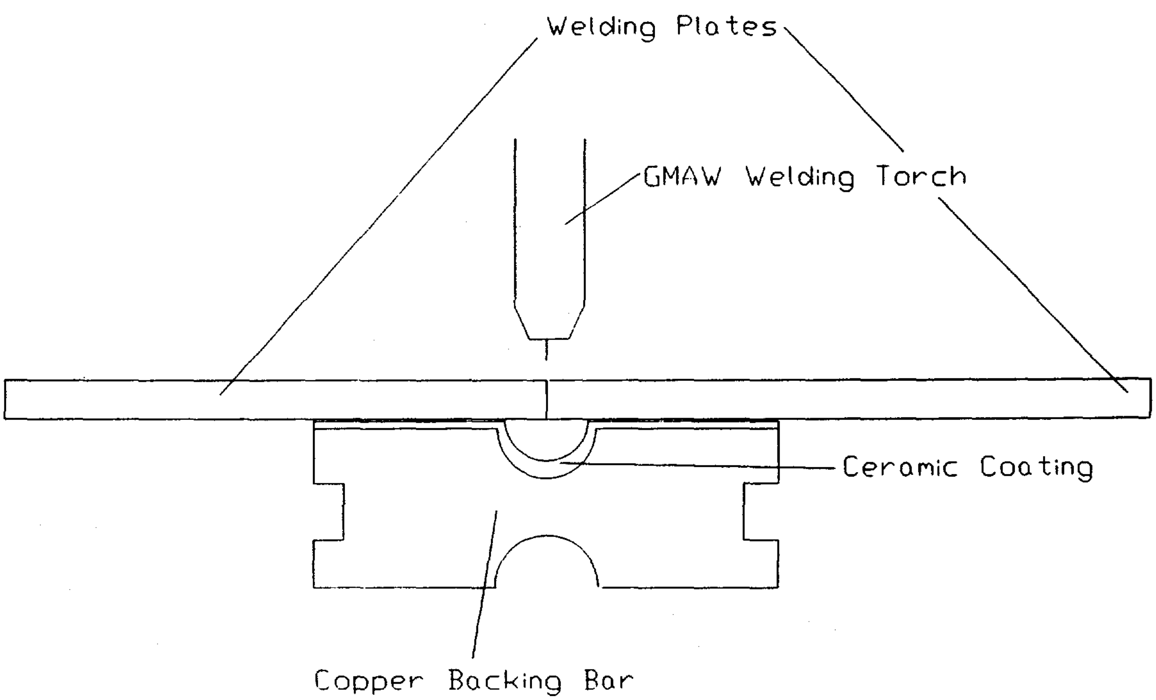

Fig. 1. In shipbuilding and many other industries, copper weld backing bars are used to draw heat out of welds.

The aim of this project is to find a way to produce backing bars with nearly the same "chilling" effect but with both a greater resistance to molten metal and resistance to arcing to the backing bar itself. A possible solution currently being tested is to coat the copper bars with a thin layer of a ceramic coating (less than 0.020 in.). Numerous processes for coating metals with ceramics exist, but the author concentrates on thermal spray processes, especially plasma spraying and High-Velocity Oxy-fuel (HVOF).

Plasma spraying uses a gun like the one shown in Fig. 2. An arc is started between the anode and the cathode, and the coating powder is shot directly into the arc. A carrier gas is blown through the arc to push the molten powder out of the plasma and onto the part. The main advantage of plasma spraying is the ability to use ceramic powders that have very high melting temperatures as a result of the extremely high temperature of the plasma. Also, compared with some older thermal spray processes, the coating created is relatively dense (90% to 95%).

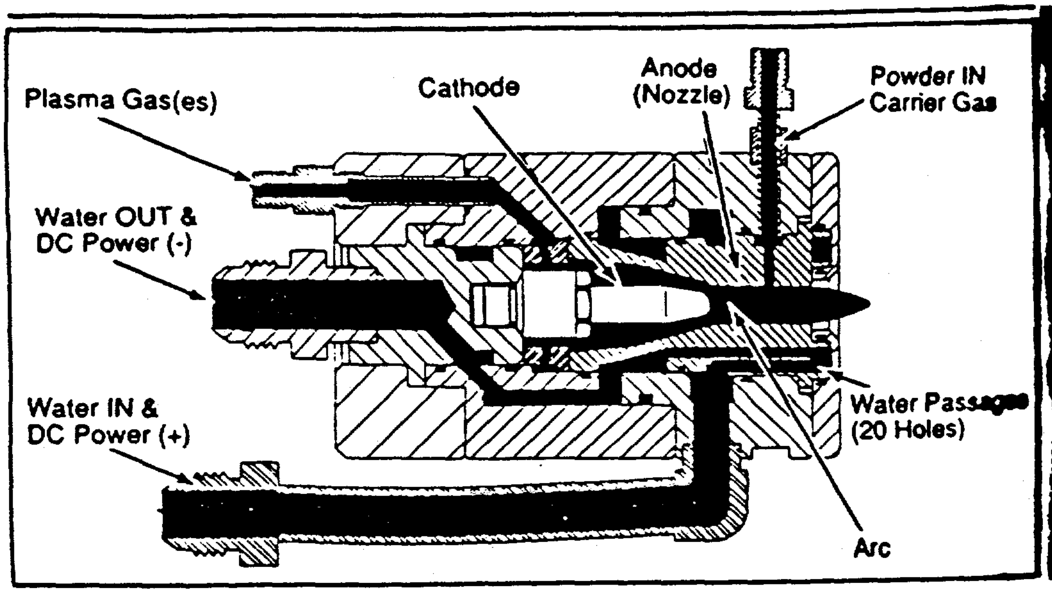

Fig. 2. Typical gun used in plasma spraying.

HVOF spraying uses a gun like the one shown in Fig. 3. As one can see, it is much like a standard oxyacetylene torch with the addition of a line that runs powder into the flame and a line that pushes the gas that blows the powder through the flame at a high velocity. The advantage of this process is that it creates coatings that are greater than 99.5% dense. The only problem with this process is that the powder is being blown at such a high velocity that it does not stay in the flame very long, meaning that some of the ceramics with high melting temperatures cannot be sprayed because they are not in the flame long enough to melt.

One of the main considerations when coating copper backing bars with a dissimilar material is the bond strength between the layers. The bond strength is directly affected by the difference in the coefficients of thermal expansions (CTEs) of the two materials. The larger the difference in CTEs, the lower the bond strength between the materials and the more likely the coating is to pop off when subjected to the thermal cycles of weld passes. One common way to minimize the problem is to use grading layers, which are layers of material with CTEs that fall between the CTEs of the substrate and the coating. These layers can be made either of totally different materials or by mixing powders of the substrate and the coating and spraying the mixture between the layers.

The following properties were determined to be the initial basis of materials selection for the coatings:

1. low electrical conductivity (an insulator),
2. high thermal conductivity, and
3. high resistance to molten steel.

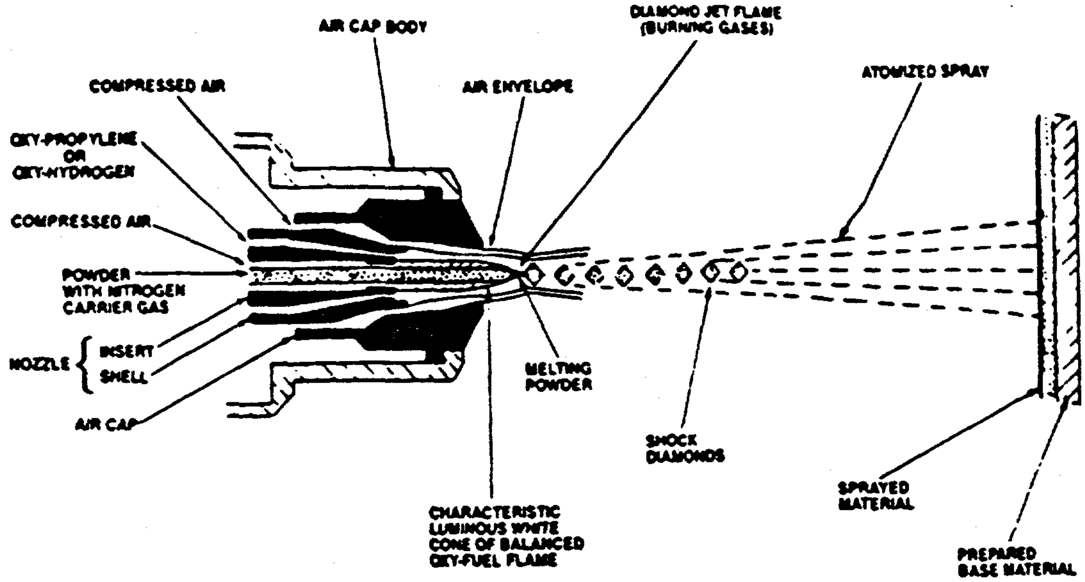

Fig. 3. Typical gun used in HVOF spraying.

Taking these properties into account, the initial materials screening brought us to a couple of good starting materials: alumina and spinel. Both of these materials have the required characteristics and are relatively inexpensive. Also, alumina is quite popular, and the spraying techniques have been perfected. The spinel is 80% alumina, but it seems to bond better and has better resistance to molten steel.

PROCEDURE

The following steps were followed to test the two chosen materials.

1. Spraying procedures were developed by spraying copper coupons with the ceramics and finding the optimum parameters.

2. The developed procedures were then used to coat the backing bar samples with different thicknesses and grade levels.

3. The coated coupons were tested for electrical conductivity. They were also subjected to scanning electron microscopy and microstructural evaluation.

4. An uncoated backing bar was welded on in an to attempt to find a procedure that would emulate the problem of sticking. The shipyards are using a gas metal arc welding (GMAW) process on high-strength, low-alloy steel.

5. These welding parameters were then used on the coated bars to determine if the bar successfully protected the bar from sticking or if the thermal cycles affected the coating.

RESULTS AND DISCUSSION

Table 1 shows the parameters that were developed from the copper coupon testing. Note that the parameters for the spray technique were used for both the alumina and the spinel because they are very similar materials. The author observed that the thicker the coating, the rougher the ceramic surface becomes. The coatings were then applied to the backing bars using the developed techniques. Table 2 shows the results.

Table 1. Parameters developed from copper coupon testing

Weld Parameters

Stickout: 0.25 in. Gun angle: 5° push Gas: 98% argon/2% oxygen

Backing Bar Statistics

Bar	Coating material	Coating thickness	Grade composition	Grade thickness
0		Uncoated backing bar		
1	Alumina	5 mils	N/A	N/A
2	Alumina	10 mils	N/A	N/A
3	Alumina	15 mils	N/A	N/A
4	Alumina	12 mils	50/50	6 mils
5	Spinel	5 mils	N/A	N/A

Welds

Weld	Current (A)	Voltage (V)	Travel speed (in./min)	Plate gap (mils)	Gas flow (psi)	Bar used	Bar temperature (°C)	Notes
1	220	27	8.7	55	55	0		*a*
2	240	28	8.7	125	60	0		*a*
3	300	32	8.7	125	60	0		*a*
4	260	29	8.7	155	60	0		*a*
5	285	30	10.0	155	60	0		*a*
6	285	30	10.0	155	60	0		*a*
7	285	30	10.0	155	60	0		*a*
8	285	30	10.0	155	60	0		*a*
9	240	27	8.7	65	60	1	70-90	*b*
10	240	27	8.7	65	60	1	87-107	*b*
11	240	27	8.7	65	60	1	108-128	*b*
12	240	27	8.7	125	60	3	65-87	*b*
13	240	27	8.7	125	60	3	111-128	*c*
14	240	27	8.7	125	60	3	121-146	*c*
15	240	27	8.7	125	60	1	90-111	*b*
16	240	27	8.7	125	60	4	108-143	*c*
17	240	27	8.7	125	60	4	115-148	*c*
18	240	27	8.7	125	60	4	124-148	*c*
19	240	27	8.7	125	60	5	141-170	*b*
20	240	27	8.7	125	60	5	142-173	*b*

a - Bar unaffected by the weld.
b - Material deposited onto the bar because of the weld.
c - Coating spawled off of the bar.

Table 2. Results of applying coatings to backing bars using the developed techniques

Initial bar thickness (in.)

Bar	Reading 1	Reading 2	Reading 3	Average
1	0.881	0.88	0.880	0.8803
2	0.880	0.88	0.880	0.8800
3	0.879	0.88	0.879	0.8793
4	0.879	0.88	0.880	0.8796

Surface profiles (mils)

Bar	Reading 1	Reading 2	Average
1	2.4	2.5	2.45
2	2.2	2.2	2.20
3	2.3	2.1	2.20
4	2.4	2.3	2.35

Compositions of coatings (Al_2O_3/Cu)

Bar	25/75	50/50	75/25	100/0
1				5 (1 ps)
2				10 (2 ps)
3				15 (3 ps)
4		6 (2ps)		12 (2 ps)

Parameters for different powder compositions

Composition (% Al_2O_3)	Standoff	Voltage (V)	Current (A)	Powder feed rate	Primary gas (Ar)	Auxillary gas (He)	Powder gas (Ar)
100	3.25 in.	25-27	850-860	0.6	41 psi	30 psi	30 psi
75							
50	3.25 in.	24-25	500-520	0.2	34 psi	88 psi	30 psi
25							

Composition (% Al_2O_3)	Gun setups
100	Miller 40 kW subsonic 10° backwards
75	
50	Miller 40 kW subsonic 10° forwards
25	

The following powders were used:
Alumina - Metco 105 SFP
Copper - 99.9% pure copper

The author was unsuccessful in his attempt to find a procedure that resulted in the same problem that occurs in the shipyard. After speaking to the welding engineer at Ingall's, the author determined that much longer pieces would need to be tested to attain the sticking problem using GMAW. Submerged arc welding was said to be much more problematic for them, which is why they use GMAW, even though it is slower, more costly, and requires more preparation on the plates.

Nonetheless, the coated bars were tested to determine the effects of both the thermal cycles and the molten steel on the coatings. Table 3 shows the weld procedures used and notes on the effect of the weld on the backing plate. As you can see, there were some problems with the bars. The bars with thicker coatings had problems with layers of coating flaking off when they were subjected to even one thermal cycle. The bars with graded coatings also flaked, much like the thicker-coated bars. The thin coatings adhered much better and were able to withstand three or four thermal cycles without flaking. All of the coated bars did seem to experience the problem of material being deposited onto the backing bar. Exactly what that material is is unknown at this time; however, it might be iron oxide formed from the molten steel and the oxygen in the ceramic.

Table 3. Weld procedures used to test coated bars

Sample thickness

Sample	Reading (in.) 1	2	3	Average
1	0.252	0.252	0.252	0.2520
2	0.251	0.251	0.251	0.2510
3	0.254	0.255	0.254	0.2543
4	0.249	0.249	0.249	0.2490
5	0.237	0.237	0.238	0.2373
6	0.253	0.253	0.252	0.2526

Note: All samples have a 2.2-mil surface preparation.

Sprayed samples

Sample	Compositions of coatings (Al_2O_3/Cu) (%) 25/75	50/50	75/25	100/0
1				6 mils
2		8 mils		? mils
3				12 mils
4				5 mils
5		34 mils		42 mils
6				

Note: Samples 1, 2, and 3 were sprayed using an automated system.

Sample	Compositions of coatings (Al_2O_3/Cu) (%) 25/75	50/50	75/25	100/0
1				1 pass
2		2 passes		? passes
3				2 passes

Parameters for automated coating passes

Composition (% Al_2O_3)	Standoff (in.)	Voltage (V)	Current (A)	Powder feed rate	Primary gas	Auxillary gas	Powder gas
100	3.5	25-27	850-860	0.75	41 psi	35 psi	20 psi
75							
50	3.5	24-25	500-520	0.24	34 psi	88 psi	30 psi
25							

Composition (% Al_2O_3)	Gun setups
100	Miller 40 kW subsonic 10° backwards
75	
50	Miller 40 kW subsonic 10° forwards
25	

CONCLUSIONS AND FUTURE CONSIDERATIONS

Although it is uncertain whether the deposited material is iron oxide, if it is determined to be such, the next step would be to look at the possibility of nonoxide ceramics. Boron carbide and molydisilicide are two possible materials for consideration. The extremely high melting temperature of boron carbide and its absence of oxygen makes it a good prospect. Molydisilicide also has great resistance to oxidation and therefore should be considered as an alternative.

Another possible problem could be that the molten steel adheres to the ceramic well because of the roughness of the coating. This problem could be avoided in one of two ways. The coated bar could be sanded to smooth the coating or an HVOF process could be used rather than the plasma-spray process now being used. The HVOF process also furnishes denser, smoother coatings, which would also be good for the thermal conduction of the material.

Another future consideration is the use of a washcoat layer of either zirconia oxide or yttria. A washcoat is a removable layer of ceramic that protects the substrate and acts as a lubricant. The washcoat would have to be reapplied at regular intervals, however, because it is a consumable coat.

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