THERMALLY SPRAYED COATINGS FOR CORROSION PROTECTION AT HIGH TEMPERATURES

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Abstract

This paper examined the suitability of thermally sprayed coatings for high-temperature corrosion protection. The coatings' resistance to abrasive wear and erosion, which, along with corrosion, are inherently damaging factors in power boilers, particularly fluidized bed boilers, was also determined. The theoretical section presents the need to modernize power generation due to the increasing requirements for operation in supercritical conditions and the consequent accelerated wear of power unit components. The system's operational scheme and the mechanisms that damage components, primarily the power boiler, during the energy production process are described. The broad application possibilities of protective coatings and their manufacturing processes are then discussed. In the research section, samples of thermally sprayed coatings were prepared by arc spraying onto S235 structural steel. Erosive wear tests were conducted at 30° and 90° angles.

Keywords: Protective coatings, hot corrosion, erosion and abrasion wear, thermal spraying, arc spraying

1. INTRODUCTION

The global increase in energy demand is forcing the technological modernization of energy systems. A key goal of optimizing power plants and combined heat and power plants is to increase the efficiency and reliability of units, which directly translates into reduced fossil fuel consumption and reduced emissions of harmful substances into the atmosphere [1]. As a result, components often must operate under supercritical pressure and temperature conditions. Operating temperatures can reach up to 750°C, and pressures exceed approximately 27 MPa. However, this translates into greater thermal and mechanical stress on the material structure, resulting in a significant increase in operating costs. Such operating parameters require new, high standards for the materials used [2]. An effective method for reducing corrosion and erosion losses is the use of protective coatings. Thermal spraying techniques are particularly important, allowing for the application of a wide range of materials to substrates of any geometry and size. The construction of power units operating at elevated temperatures places high demands on the materials used [3]. In classical steam systems, the chemical energy of the fuel is converted into electrical energy in a clockwise comparative cycle. The process involves steam generation in a boiler, its expansion in a turbine coupled to a generator, and condensation in a water-cooled condenser [4,5]. Degradation of energy system components most often occurs as a result of the synergistic interaction of friction, corrosion, and, in the case of boilers, high-temperature corrosion. Particularly intense co-occurrence of erosion and corrosion (tribocorrosion) is observed in solid fuel power boilers, especially fluidized-bed boilers, where surfaces are exposed to simultaneous contact with a chemically aggressive environment and dynamic flow of solid particles [6]. For economic reasons and policies encouraging the use of renewable fuels, an increasing number of boiler plants are choosing to burn or co-fire biomass. This has significant environmental benefits, as biomass is considered a zero-CO_2 fuel, as well as social benefits, including new jobs. A negative effect is the increased risk of high-temperature corrosion of boiler heating surfaces by up to an order of magnitude. This problem is of great importance in both local boiler plants and the power industry, where co-firing biomass can dramatically shorten the service life of evaporator screen tubes by 2-3 years [6]. Various efforts are being made to reduce material consumption, ranging from design changes to appropriate material selection and the application of protective coatings. Effective development of protective coatings will require the implementation of DOE methods [7,8] and consideration of modification of these coatings by laser micromachining [9,10].

2. PROCEDURE OF THE EXPERIMENT

The aim of this study is to investigate the resistance of thermally sprayed coatings applied using the arc method to structural steel used in the production of power boilers. The study compared the coatings for their resistance to abrasion and erosion. High-temperature corrosion and its impact on the durability of the coatings were also analyzed. These phenomena are ubiquitous during fuel combustion in power boilers. Material loss and the formation of corrosion products were compared, and the coatings' suitability for practical use was assessed. The base material used for thermal spraying was S235JRG2 structural carbon steel in the form of flat bars. This steel was initially prepared and then sprayed with individual coating types using the arc thermal spray process. The coated steel was then cut into 50 x 3 mm samples, and three of each coating type were prepared for laboratory testing for resistance to erosion and high-temperature corrosion. The list of tested coating variants is presented in **Table 1 and Figure 1**.

To assess the suitability of the developed coatings for erosive and abrasive wear, as well as high temperatures, laboratory tests were conducted simulating actual operating conditions. Two wear tests were selected as typical:

- erosive wear at ambient temperature, and
- abrasive wear performed on a T-07 tester at room temperature.

The adopted test methods involved comparing the absolute wear of various coatings under identical test conditions. The wear resistance of the coatings was measured by the weight loss of the samples. Erosive wear resistance was evaluated on a specially designed test stand that enables testing at abrasive impact angles of 90° and 30° at room temperature. Erosive wear tests on the coatings were conducted under constant test conditions, selected to avoid damaging the sample substrate. These were as follows:

- air pressure - 0.6 MPa,
- nozzle-to-sample distance - 0.04 m,
- abrasive mass - 50 g,
- abrasive type - corundum
- spray angles - 90° and 30°.

Before testing, each sample was weighed four times on a laboratory scale, accurate to four decimal places. Weight measurements were also taken after the tests, in the same manner as before. The difference between the weight measurements before and after the test was used to calculate the mass loss, a measure of the coatings' resistance to erosive wear.

Table 1 Coating systems used in the presented investigations

System	**Fe**	**Cr**	**Ni**	**B**	**Mo**	**Nb**	**W**	**C**
SP-101	Bal.	22	0.5	4.5	4	3.5	6.5	1.2
	Fe	**Cr**	**Si**	**B**	**Mn**	**C**		
AS-812	Bal.	28.75	1.5	3.8	1.5	0.1		
	Ni	**Cr**	**B**	**WC**				
AS-761	Bal.	10	2.0	50				
	Fe	**Cr**	**C**	**Mn**	**other**			
Metco 8220	**-**	**-**	**-**	**-**	**-**	-	-	-
	-	**-**	**-**	**-**	**-**	-	-	-
Metco 8222	Bal.	28	5	1	1.5			
	Fe	**Cr**	**Ni**	**B**	**Si**	**WC**	**TiC**	
Metco 8297	Bal	13	6	2	1	26	6	
	Ni	**Cr**	**Mo**	**Nb+Ta**				
IN625	Bal.	21	9	4				
	Ni	**Cr**	**Ti**					
SP-224	Bal.	45	1					

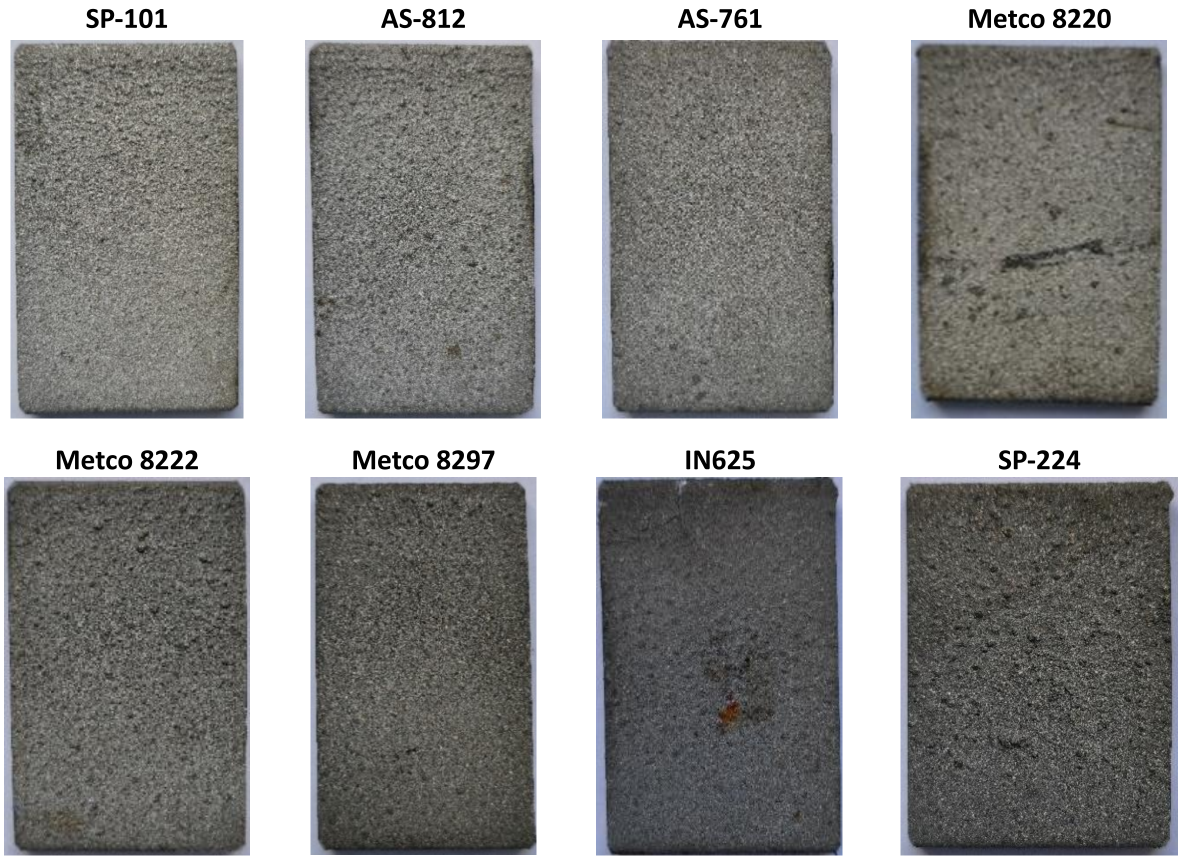

Figure 1 Overall view of analyzed coating systems

3. RESULTS

The results of 90° erosion resistance tests are presented in **Table 2**. Coatings containing nickel and chromium as a base element or in significant percentages demonstrate high erosive wear resistance, characterized by the lowest average mass loss, particularly at an abrasive angle of incidence of 90°C. These coatings include Inconel 625 and SP 224. Coatings containing iron as a base element or at significant percentages exhibit about half the erosive wear resistance, resulting in nearly twice the average mass loss. These coatings include SP 101, Metco 8297, and Metco 8222. The Metco 8280 coating also demonstrates very good resistance to erosive wear. It can be concluded that this is due to its specific structure, which is amorphous and contains adhesive particles that reinforce the structure. The results of 30° erosion resistance tests are presented in **Table 3**. Coatings containing nickel and chromium as a base element or present in a significant percentage demonstrate high erosive wear resistance, characterized by the lowest average mass loss, particularly at an abrasive angle of incidence of 90°C. These coatings include Inconel 625 and SP 224.

Coatings containing iron as a base element, or present in a significant percentage, exhibit about half the erosive wear resistance, resulting in an average mass loss nearly twice as high. These coatings include SP 101, Metco 8297, and Metco 8222. Metco 8280 also demonstrates very good resistance to erosive wear. It can be concluded that this is due to its specific structure, which is amorphous and contains adhesive particles that reinforce the structure.

4. SUMMARY

During research on thermally sprayed metallic coatings produced by the arc method, it was necessary to determine their performance under abrasive wear and high-temperature corrosion. These phenomena are the main factors that damage system components during power boiler operation, causing failures and interruptions in electricity supply.

Erosion testing was performed at room temperature at 30° and 90° angles to obtain a broader spectrum of erosion mechanisms. It should be emphasized that in real-world operating conditions, high temperatures are present, intensifying the erosion process.

The following observations were made from the results obtained:

- The nickel and chromium content in the coating structure has a strengthening effect, creating a material highly resistant to erosive wear.
- Iron-based coatings, despite containing nickel and chromium, exhibit almost half the erosion resistance at both 30° and 90° angles of abrasive impact compared to coatings with trace amounts of this element. Studies have shown that these are the least resistant materials to erosive wear.

It is known that in laboratory settings, we cannot fully replicate the conditions that prevail during fuel combustion. This process always involves deviations from basic parameters, depending on fuel quality, the air added to the fuel mixture, and the condition of the materials used in constructing the energy system components. However, it is impossible to study actual process conditions due to the size of components such as a power boiler, and system downtime is also impossible for economic reasons.

Therefore, laboratory test results should be treated with a margin of error, applied to the production of protective coatings, and the actual operation of these coatings in energy systems should be monitored.

Table 2 Average mass loss of coatings due to erosive wear at an angle of 90° of abrasive incidence

System	Overall view	No	Average weight before test [g]	Average weight after test [g]	Mass gain [g]	Mass gain [%]	Average mass gain [%]
SP 101		1	62.2041	62.1298	0.0743	7.4275	5.13
		2	64.7023	64.6602	0.0421	4.2125	
		3	61.7983	61.7608	0.0374	3.7425	
AS 812		1	62.0955	62.0594	0.0361	3.6150	3.61
		2	61.4096	61.3754	0.0342	3.4175	
		3	61.1500	61.1119	0.0381	3.8050	
AS 761		1	62.5275	62.4815	0.0459	4.5925	4.43
		2	62.1761	62.1364	0.0396	3.9650	
		3	62.8816	62.8343	0.0473	4.7275	
METCO 8280		1	62.5131	62.4827	0.0304	3.0425	2.81
		2	61.7725	61.7456	0.0269	2.6925	
		3	62.4180	62.3910	0.0270	2.7000	
METCO 8222		1	62.0956	62.0517	0.0439	4.3900	4.55
		2	62.0053	61.9590	0.0463	4.6300	
		3	61.7447	61.6983	0.0464	4.6400	
METCO 8297		1	64.0723	64.0189	0.0534	5.3425	4.91
		2	62.9404	62.8835	0.0569	5.6950	
		3	62.2248	62.1878	0.0369	3.6950	
SP 224		1	40.6008	40.5779	0.0229	2.2900	2.23
		2	40.9155	40.8937	0.0219	2.1875	
		3	40.4692	40.4471	0.0221	2.2050	
INCONEL 625		1	42.7832	42.7618	0.0214	2.1400	1.96
		2	42.0122	41.9937	0.0185	1.8525	
		3	42.1602	42.1413	0.0189	1.8925	
STAL		1	59.3426	59.3109	0.0317	3.1700	3.26
		2	56.9381	56.9071	0.0310	3.0950	
		3	57.5787	57.5442	0.0345	3.4475	

Table 3 Average mass loss of coatings due to erosive wear at an angle of 30° of abrasive incidence

System	Overall view	No	Average weight before test [g]	Average weight after test [g]	Mass gain [g]	Mass gain [%]	Average mass gain [%]
SP 101		1	63.55973	63.51658	0.04315	4.31	4.67
		2	63.23080	63.18055	0.05025	5.03	
AS 812		1	61.90805	61.86540	0.04265	4.27	4.33
		2	62.77090	62.72705	0.04385	4.38	
AS 761		1	64.38208	64.33383	0.04825	4.82	5.03
		2	65.73033	65.67798	0.05235	5.23	
METCO 8280		1	61.19128	61.15083	0.04045	4.04	3.76
		2	63.61525	63.58040	0.03485	3.49	
METCO 8222		1	64.89975	64.85038	0.04937	4.94	5.02
		2	62.27775	62.22678	0.05098	5.10	
METCO 8297		1	63.31393	63.26058	0.05335	5.33	5.46
		2	62.12660	62.07075	0.05585	5.58	
SP 224		1	42.24470	42.20783	0.03687	3.69	3.68
		2	41.39680	41.36000	0.03680	3.68	
INCONEL 625		1	44.47665	44.44658	0.03008	3.01	3.39
		2	44.31670	44.27893	0.03777	3.78	
STAL		1	40.12495	40.07525	0.04970	4.97	4.55
		2	30.40913	30.36783	0.04130	4.13	

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