A Conductive Composite Material for Wet ESP Applications

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1 Summary/Abstract

This paper discusses the development of a new carbon composite conductive material for use in wet electrostatic precipitators (WESPs). The objective was to develop a low cost alternative exhibiting improved properties compared to stainless steels and lead. After laboratory evaluation, field trials were undertaken using commercial-grade WESP tubes at two industrial sites. The material was further improved to increase arc resistance, while maintaining corrosion resistance and conductive properties. This new material, found to have better arc resistance than SS304L stainless steel, was used to manufacture a tube bundle and installed in a pilot WESP system.

2 Background

Wet electrostatic precipitators have been used for many years to remove dust, acid mist and other particulates from water-saturated air and other gases by electrostatic means. In a WESP, particulate and/or mist laden water-saturated air flows in a region of the precipitator between discharge and collecting electrodes, where the particulates and/or mist is electrically charged by corona emitted from the high voltage discharge electrodes. As the water-saturated gas flows further within the WESP, the charged particulate matter and/or mist is electrostatically attracted to grounded collecting plates or electrodes where it is collected. The accumulated materials are continuously washed off by both an irrigating film of water and periodic flushing.

WESPs are used to remove pollutants from the gas streams discharged from various industrial sources, such as incinerators, wood products manufacturing, coke ovens, glass furnaces, non-ferrous metallurgical plants, coal-fired power generation plants, forest product facilities, food drying plants and petrochemical plants.

Traditionally, the collecting surfaces and other parts of electrostatic precipitators exposed to the process gas stream have been fabricated from carbon steel, stainless steel, corrosion and temperature resistant alloys and lead. However, such materials tend to corrode and/or degrade (creep) over time, especially when the precipitators are operating in severe environments.

Other methods have been used to fabricate collecting surfaces involving the use of plastic materials; however, these materials rely on a continuous water film to ensure electrical grounding of the equipment, which has proved to be a problem. PVC, polypropylene and other similar materials have been used but have suffered from holes and flashover-induced fires and therefore are not widely used.[1]

A novel design, using membrane collecting surfaces providing capillary fluid transport was patented by researchers at Ohio University.[2] Although full-scale operating results on an oil-fired boiler[3] have been demonstrated, this design has not yet been used extensively.

Additional material strategies have been employed, such as the use of carbon to benefit from its electrical conductivity and high corrosion resistance.[4]

Trials using carbon powder impregnated glass reinforced plastic (GRP), while providing good initial performance, developed significant holes from arcing, which leads to reduced performance as a result of build-up on the tubes and deterioration of the glass reinforcement.

Encouraging results have been obtained using electrically conductive fiberglass composite and/or carbon fibers with nano fibers or nano tubes to enhance corona generation of emitting electrodes.[5, 6]

The use of carbon fiber-based materials for the collecting electrodes presents a significant additional challenge, not only must they be corrosion resistant under severe industrial environments and electrically conductive, but they must also be resistant to localized high temperatures due to electrical arcing and have the ability to rapidly dissipate the energy thereby generated.

3 Initial Trials

During the initial development phase, a number of materials were identified as candidates for use, including various reinforced plastic/epoxy/carbon combinations, carbon impregnated GRP, and various combinations of carbon/epoxy samples, some with layers of thin wire mat.

A procedure was developed to identify materials suitable for further study. This involved using a point-to-disk apparatus, which was set up in the high voltage laboratory at the University of Waterloo, Waterloo, ON Canada.

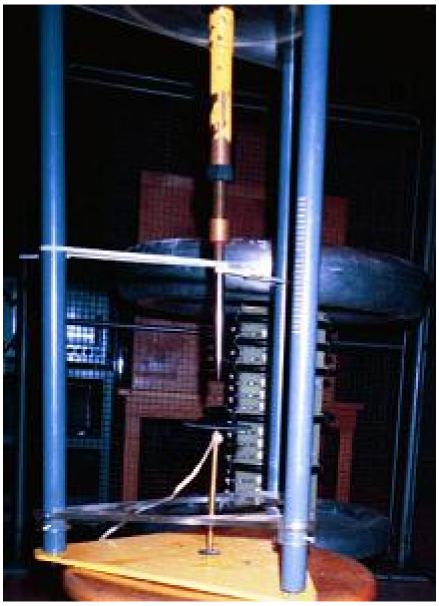

Fig. 3-1: Test Apparatus

The average measured voltage gradient was 6,7kV/cm, with disks or “pucks” of sample material 80mm x 10cm diameter.

The test gap between the discharge point and the test sample disc was set in the range of 30-70kV, similar to a full-scale WESP installation. The voltage was provided by a 300kV DC power supply.

The surface and volume conductivity were recorded for each sample. Voltage-current data was also obtained and characteristic (kV vs. mA/m^2) curves recorded. Samples were then placed in the test apparatus in which spark testing was carried out for a specific period of time at 50-60 sparks per minute (SPM) at voltage and specific current levels similar to a full scale WESP. The degree of spark erosion was then compared to that of a carbon impregnated FRP sample, made from commercially available material. The examination and comparison was carried out visually, unaided and with a microscope.

After extensive evaluation carried was out over 2-3 years, a carbon nanotube/epoxy composite mix was found to have both volume and surface conductivity similar to that of steel, with no evidence of significant spark erosion. This material was selected for further evaluation.

4 In-situ Testing

Two round tubes were fabricated from the selected material for installation in full-scale operating WESP installations. The tubes were installed in a manner similar to that shown in Figure 4-1, which shows a sample tube being checked for fit in the laboratory. It is to be noted that the tubes in the full-scale WESPs are of a hexagonal design.

Fig. 4-1: Hexagonal Tube and Composite Sample in the Laboratory

Two full-scale WESP installations were selected for test trials.

The first test site, at a plant producing thermal insulation material, was an exceptionally corrosive application, the gas stream containing fluorides and chlorides with the WESP discharging liquid of pH < 0,4. The tube was intentionally “power arced” immediately after installation with no apparent effect. The discharge electrode was offset, forcing all flashover to occur in the sample tube. This installation is shown in Figure 4-2; it is to be noted that the WESP tubes are lead, due to the extremely corrosive environment.

A second tube was installed in a similar manner in a WESP cleaning exhaust gas from a power boiler burning salt-laden bio-fuel and coal at a pulp mill.

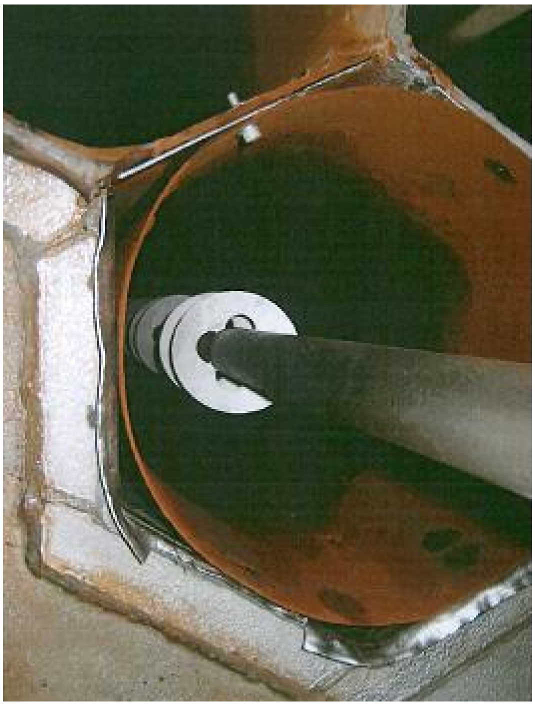

Fig. 4-2:Lead Hex Tubes and Composite Sample at Test Site

After a 10-month trial period, it was found that the structural and mechanical integrity and corrosion resistance was satisfactory; however, arc resistance was poor and holes were found in both tubes.

5 Additional Testing

The field trials demonstrated that the selected material suffered from poor resistance to electrical arcs, and that resistance to power arcing, rather than sparking, was required. Sparking can be defined as a relatively small discharge within the precipitator that will self-extinguish with no increase in the base waveform current. An arc may be described as a large disruptive discharge within the precipitator that will not self extinguish. This latter definition was used as the criteria for further development, requiring a laboratory set-up to simulate it.

The second phase experimental studies were carried out in a laboratory at TurboSonic's facility in Waterloo, ON Canada. A single 3m long 250mm hexagonal collecting tube was set up on a laboratory test stand, powered by a 50kV, 8mA NWL transformer/rectifier (T/R) set.

A capacitor bank was installed in parallel with the hexagonal tube, in accordance with Figure 5-1. The capacitance was equivalent to approximately 277 tubes, each 5m long and 250mm equivalent diameter. A pointed discharge spike was installed on the mast (emitting) electrode, adjacent to which composite samples were mounted on the test collecting tube. Power arcs generated approximately 67 Joules to be dissipated at the point of arc contact on the sample. The controller on the T/R set was such that arcs could be counted: these power arcs were robust in nature and sufficiently loud that the integrated arc count reading on the controller could be verified using a stopwatch and manual spark count.

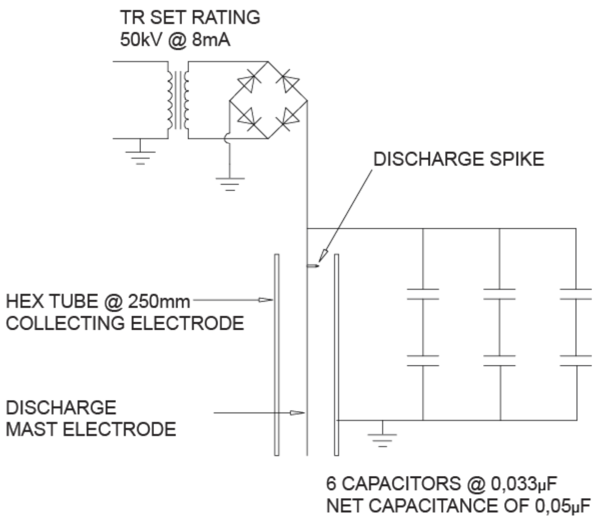

Fig. 5-1:Test Rig Setup

SS304L was used as the basis of comparison. It was found that 3400 arcs caused pitting, 10000 arcs caused severe pitting and metal damage, and 13000 arcs resulted in extensive metal damage. The damage at 10000 arcs was quite significant; this level of arcing is not normally experienced in full scale WESP operation. This level was arbitrarily used as the standard for further arc resistance comparative testing.

Visual observations and photographs were made of additional samples of modified composite construction tested at 10000 power arcs.

In an effort to understand the mechanisms involved, some of the samples were tested at a different arc count and evaluated microscopically.

6 Nature of Arc Erosion

Three samples used in the power-arc testing were selected for further analysis.[7] Two of the samples were made from woven 2x2 twill carbon fiber with a high heat distortion corrosion resistant, epoxy vinyl ester resin (Sample 1 and Sample 2). The third control sample (Sample B1-A, B) was cut from an existing tube constructed of 1x4 twill carbon fiber. After arc testing, the samples were analyzed under an optical microscope to further understand the mechanism providing the carbon composite laminates with their high level of arc endurance.

Overall, the erosions for Sample 1 with 2120 arcs were relatively small compared to the surface area tested and the thickness of the laminate. Crude surface erosion area estimates give 200 to 1400 arcs per mm^2 of surface erosion. The amount of arc erosion in Sample 1 is comparatively close to previous carbon composite laminate Sample B1-A (3000 arcs).

The main difference between the arc erosion of the previous laminate Sample B1-A, B (1x4 Twill) and Sample 1 (2x2 Twill) was the location of the main erosion concentrations. Sample B1-A, B arc erosions were focused mainly on the fabric's tows (bundle of fibers) running in the Twill-1 direction (also tube axial direction) and the Twill-4 direction was relatively clear of any major erosion. In contrast to this Sample 1 (2x2 Twill) arc erosions were evenly distributed on both the warp and the weft directions.

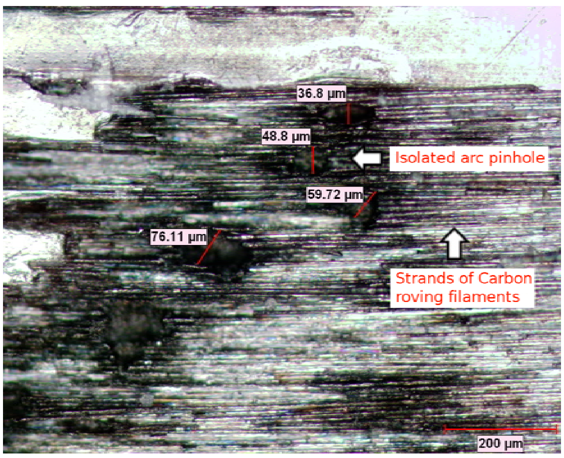

Fig. 6-1: Sample 1 (100x) – Produced by Bellshire Technologies Inc. Note: For maximum contrast, the colours were equalized.

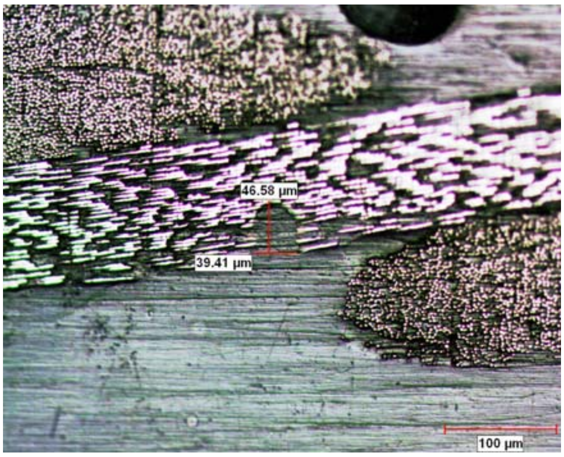

Fig. 6-2: Sample 1 – Produced by Bellshire Technologies Inc. Note: For maximum contrast, the colours were equalized.

With Sample 1, the arc erosions formed straight lines running transversely to the targeted surface tow. The erosions had a tendency to form two parallel lines. Each of these lines was associated with corresponding tows in the tow layer beneath.

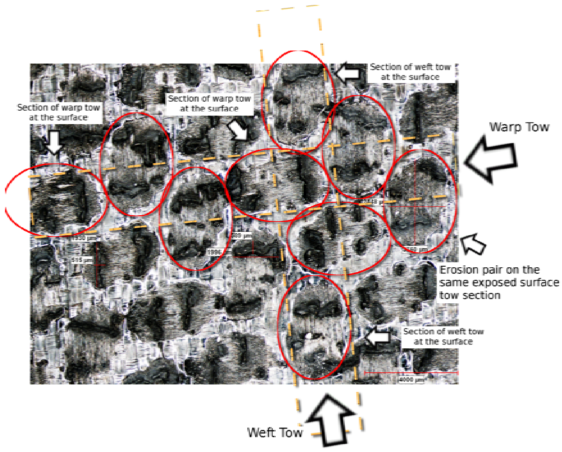

Fig. 6-3: Sample 2 (6.3x; 10041 arcs) – Produced by Bellshire Technologies Inc. Note: For maximum contrast, the colours were equalized.

In sample 1, the cross section of the linear erosion agglomeration in the tow's transverse direction was found to be well a defined "V" with a depth of the observed burns ranging from 46 to 113µm with an opening of 39 to 285µm. The maximum erosion depth observed was relatively small, with only 3.9% of the laminate thickness and 15.6% of the surface lamina thickness eroded. The cross section of the linear erosion agglomeration in the tow's longitudinal direction was found to be less well defined. The length of the observed burns are approximately in the 380µm with varying depth across its length.

With the addition of more arc (Sample 1 @ 2120 arcs vs. Sample 2 @ 10041 arcs), the majority of the traits seen at 2120 arcs were duplicated; however, the size of the erosions increased and the maximum observed cross sectional depth of an erosion increased to 364,2µm. This translates to 11% of the laminate and 2/3 of the surface lamina.

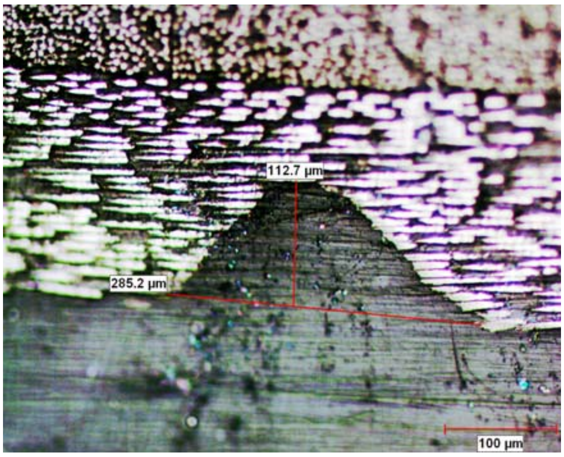

Fig. 6-4: Sample 1 – Produced by Bellshire Technologies Inc. Note: For maximum contrast, the colours were equalized.

Sample 2 had an additional trend from that seen in Sample 1. Once the erosion depth reached tows running in the opposite fabric direction, the path of the erosion changed to be transverse to that newly targeted lower tow. This created right angle turns and branches in the erosion lines running in either the warp or weft directions.

The above findings create the possibility of controlling the erosion density and direction by controlling the weave pattern and the fabric's thickness. As seen in Sample 2, each crossover point in the weave contained one erosion line. Hence it can be surmised that a tighter weave will create a greater density of erosion lines. The thicker fabrics will also create erosion lines with fewer turns and branching.

After arc testing of Sample 2 the only observation to the naked eye was surface discoloration caused by the sample's loss of luster, or sheen. Since the damage was so small, it was concluded that the new conductive composite has better resistance to arc erosion than SS304L.

The adhesive bonding of sub components is a major aspect in the assembly of the new WESP design. To evaluate the joint's arc performance, two sample plaques were bonded together using a conductive bonding formulation. One sample had a joint line as thin as possible (< 0,25mm) and another had a thick joint line (approximately 1,25mm).

Two corrosion resistant conductive bonding formulations were tested. One variant with a blend of conductive carbon fillers and another with a carbon nanotubes/conductive carbon filler blend, which was formulated to the same material cost point as the first.

Prior to applying the bonding formulation, the substrate plaques were sanded to remove insulative surface resin. The sanding stopped once 80% of the surface showed ansiotropic reflection caused by the exposure of the carbon fibers. The conductivity of the surface was tested in multiple locations to confirm that the majority of the insulative resin was removed.

The joints were subjected to 10000 power arcs in the test facility, at an electrical condition approximating the full-scale application. Visual observations showed similar arc erosion to the non-bonded laminates. It was therefore decided to proceed with fabrication.

7 Pilot Test WESP

Based on the foregoing macro and microscopic examinations, the selected material composition was used to fabricate a collecting tube bundle, as shown in Figure 7-1. This tube bundle was installed in a pilot test WESP, as illustrated in Figure 7-2, and was statically tested, the results of which were similar to that for a SS304L tube bundle.

Fig. 7-1: Composite Hex Tube Bundle

Successful dynamic tests were also carried out using saturated ambient air.

The pilot WESP is a “slice“ of a full-scale installation in that the 300mm nominal diameter hexagonal tubes at approximately 5m in length are similar to that used in a full-scale installation. (See Figure 7-2) The pilot WESP has a gas flow capacity of 3000m^3/hr (saturated) and is completely automated. It includes a pre-scrubber, variable speed fan and stack. The PLC/HMI control systems monitors operating parameters and is interfaced with built in MCC and T/R controls. The input transformer is capable of accepting most international voltages and frequencies.

Fig. 7-2: Pilot WESP

8 Conclusions

A new conductive carbon composite material has been developed for the manufacture of WESP collecting electrodes. Conductivity and resistance to power arcing are superior to SS304L, while corrosion resistance is determined by resin selection and would equal or exceed that for lead and high nickel stainless steels.

A vertical flow hexagonal tube demonstration WESP has been fabricated using this new material. Field trials have been planned.

9 References

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