CuproBraze® Heat Exchanger Technology

EXECUTIVE REPORT

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New DuraFin™ Heat Exchangers for Mining Vehicles

DuraFin™ is a brand name for heavy duty heat exchangers, designed especially for mining vehicles operating in extremely harsh environmental conditions. The heat exchangers are manufactured with *Cu*proBraze® technology utilizing high-strength and high-conductivity copper alloys, facilitating strong, efficient and compact products, manufactured with an environmentally friendly process. The new copper alloys, developed for this technology, offer high strength as well as excellent retention of strength even at elevated operating temperatures up to 300 °C. The corrosion resistance is maximized by utilizing special organic coating for the entire external surface of the heat exchangers, not only the core faces, like on conventional heat exchangers. In addition, on charge air coolers the turbulators inside the tubes have a special corrosion resistant metallic coating. This concept has proven to withstand the most demanding atmospheric conditions in underground mines, involving high humidity, high ambient and operational temperature, salts, hydrogen sulfide and dust.

Why DuraFin™ was developed?
There are varying conditions in mines, depending on the type of soil, depth from surface, temperature, humidity, pollutants etc. In the harshest conditions the lifetime of the mining vehicles can be limited to two or three years involving a lot of maintenance and replacement of components during the lifetime. Therefore, it would be desirable, that the components lasted as long time as the vehicle itself. That would maximize the utilization of the vehicle for its actual mission and reduce operational costs.

Environmental conditions

Finnradiator Oy, a member company of *Cu*proBraze® Alliance, faced this durability issue when it supplied heat exchangers to a copper mine which was extremely corrosive. Conventionally protected copper fins on heat exchangers practically faded away within three months. Aluminium had been facing the same problem. A common solution has been to use thicker construction materials at the sacrifice of thermal performance, weight and size.

The copper-bearing soil in this particular case comprises three separate lithological layers: sandstones at the base, clay-marl or dolomitic shales and dolomitic limestone in upper part. Copper mineralization is the strongest in the black clay shales which, therefore, are named the Copper-bearing Shales. The major copper minerals of the ores include: chalcocite (Cu_2S), bornite (Cu_5FeS_4) and chalcopyrite ($CuFeS_2$). They are accompanied by numerous other minerals of copper, silver, lead, zinc cobalt and nickel. These porous soils enable high humidity and sulphuric pollutants in the mine atmosphere.

Fig. 1. : Some environments, like certain copper mines can be very corrosive. The lifetime of the entire mining vehicle can be limited to only two to three years. Ordinary heat exchangers, irrespective of material, can corrode to useless condition within a couple of months. The heat exchanger on picture was operated in mining vehicle for three months. The fins were totally deteriorated.

Development phase

This challenge with corrosion resistance triggered a new development in co-operation between Finnradiator and a mining vehicle manufacturer. In scientific analysis of the failure mode, in close co-operation with VTT Expert Services Oy of Finland, it was detected that the *Cu*proBraze® brass tubes and *Cu*proBraze® brazing alloy were fully resistant to the harsh environment in question. The material which suffered from corrosion was copper on external fins and on turbulators inside the charge air cooler tubes. Therefore, the further development was focused on creating an additional protection method for copper for the harsh conditions.

It was concluded that coatings would be the practical solutions to the problems. From coating application point of view, the requirement for the external coating was that it must be able to be applied on all exposed fin surfaces on a thick heat exchanger core with six tube rows. On the radiator in question the external exposed area was about 60 m^2.

A conventional spray coating is more or less cosmetic and covers only the core faces. It penetrates only a few millimetres inside the core, i.e. it covers only a few percent of the total area. A functional criterion for the coating was that it must not adversely affect the thermal performance or increase the air pressure drop of the heat exchanger.

In practice all this means that the coating had to be optimized for this application. It must be thick enough to provide the corrosion prevention but thin enough not to destroy the thermal characteristics.

Finnradiator had long term know-how and experience from this kind of development and was able to define a conceptual solution quite rapidly. An organic coating type and application method were defined. Wind tunnel test results were the basis for the targeted average coating thickness.

The selected coating was applied at first to small heat exchangers. After coating the heat exchanger cores were cut in pieces to check the penetration of the coating.

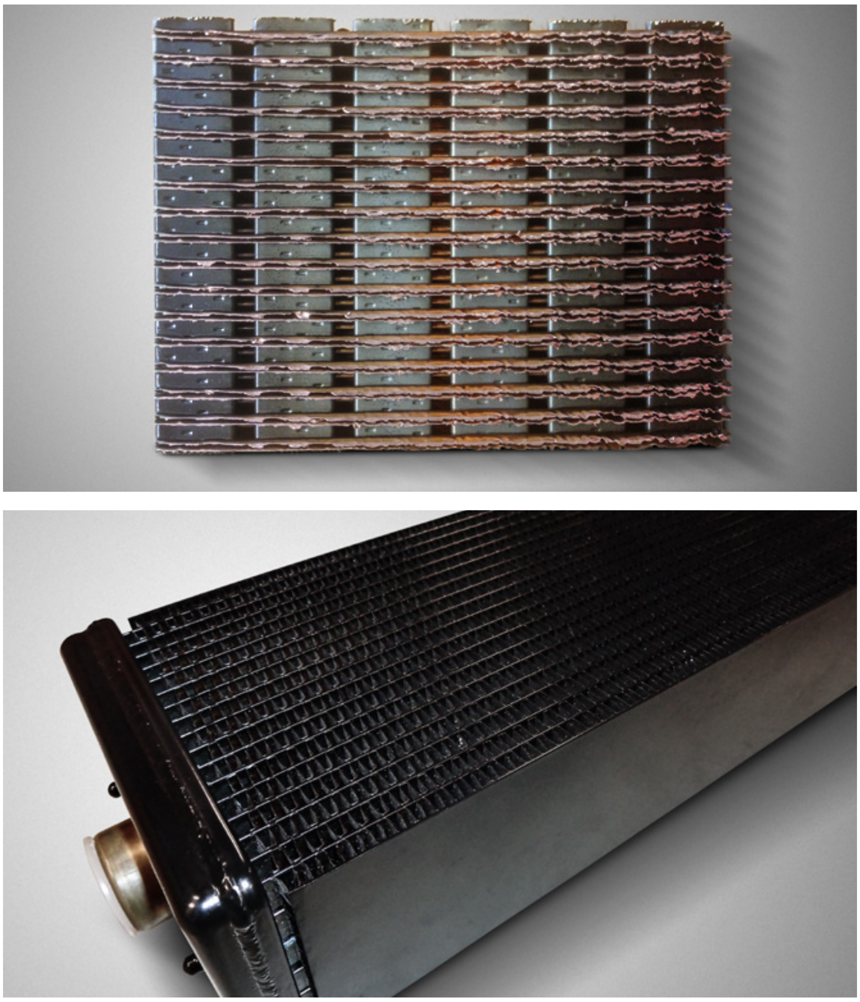

Fig. 2. Coated mid-size radiator with six tube rows. The black appearance of the tubes on the cross section in the right demonstrates the complete penetration of the coating through the core.

Gradually larger heat exchangers were coated and the coating process parameters were established for different core constructions and core sizes. This process took about 18 months. The corrosion resistance of the coating was ensured by installing coated copper plates to the inlet air channel of the cooling system on the same type of mining vehicle and in the same mine, where the problem had originally been discovered. After three months' test time it was observed that the coating really had protected the fin material from corrosion.

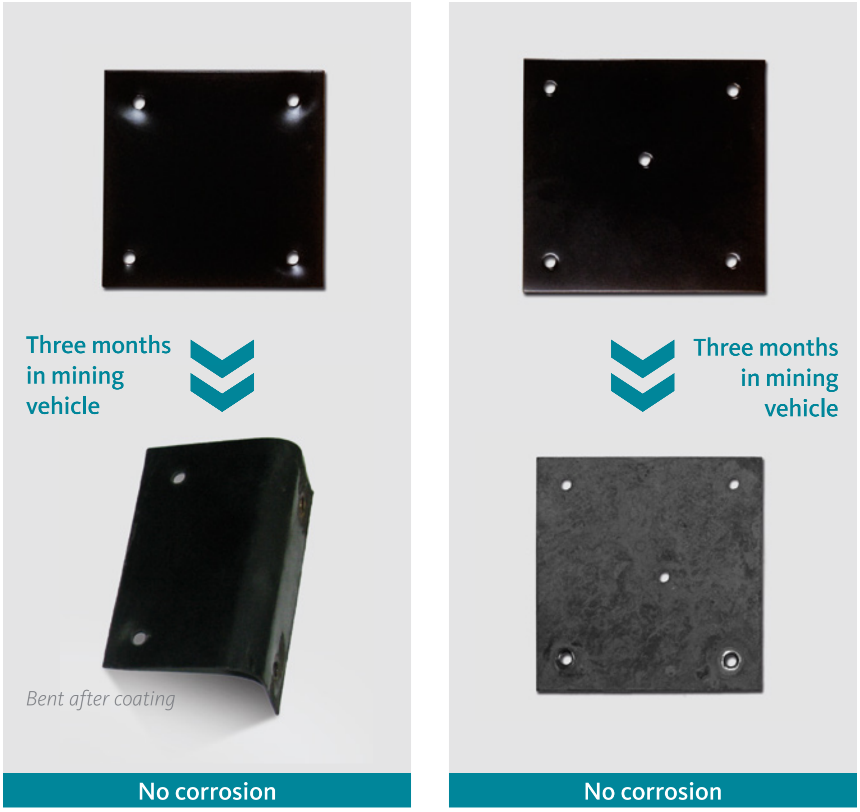

Fig. 3. Coating test in real field conditions gave favourable results. The coating was corrosion resistant and is rather elastic. The lower sample in the right was bent 90 degrees after coating application and then field tested, demonstrating the tough nature of the coating.

Analogical development was done for the copper turbulators used inside charge air cooler tubes. The concept for this application had been developed and patented earlier by Aurubis and Denso. Finnradiator was granted a license to proceed with the development and testing to production scale. In this case the coating is metallic. A special after treatment after coating application is needed to establish and adjust the final protective characteristics.

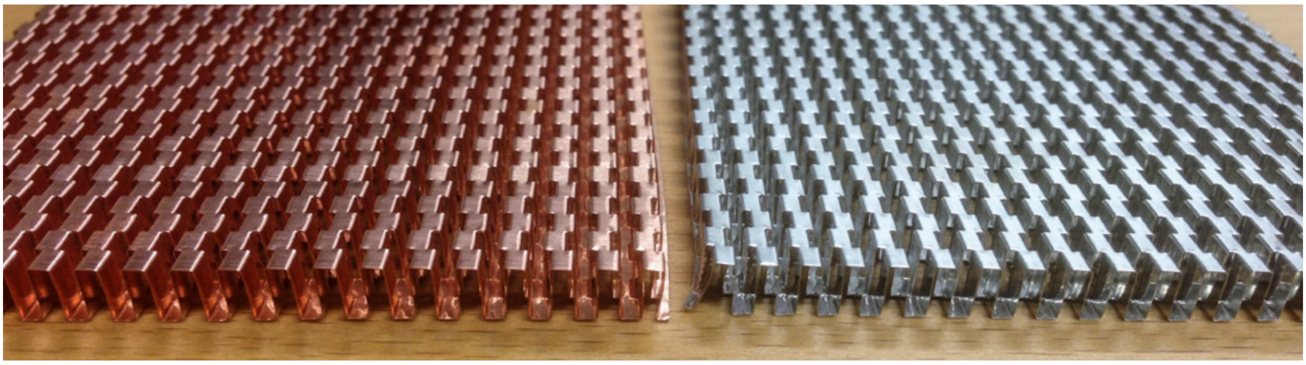

Fig. 4. Turbulators are used inside the charge air cooler tubes. The picture shows an uncoated (left) and coated (right) turbulator. The metallic coating is additionally after treated to achieve the required corrosion prevention characteristics. The coated turbulator has an excellent adherence to the tube after brazing.

Laboratory scale tests by the inventors in simulated EGR*-condensate environment had shown that the special coating stops the corrosion from penetrating through the fin. Instead of pitting, the corrosion is redirected to follow the surface of the fin. Thus the attack is spreading to larger surface area and is resulting only in superficial corrosion.

It was expected that this mechanism would also work in the mining environment and probably other extremely corrosive environments, not only in a laboratory test. At the same time with the organic coating test, coated turbulator material was tested in the real mining vehicle and mine for three months. The test confirmed that this was a feasible solution to give the desired additional lifetime to the turbulators.

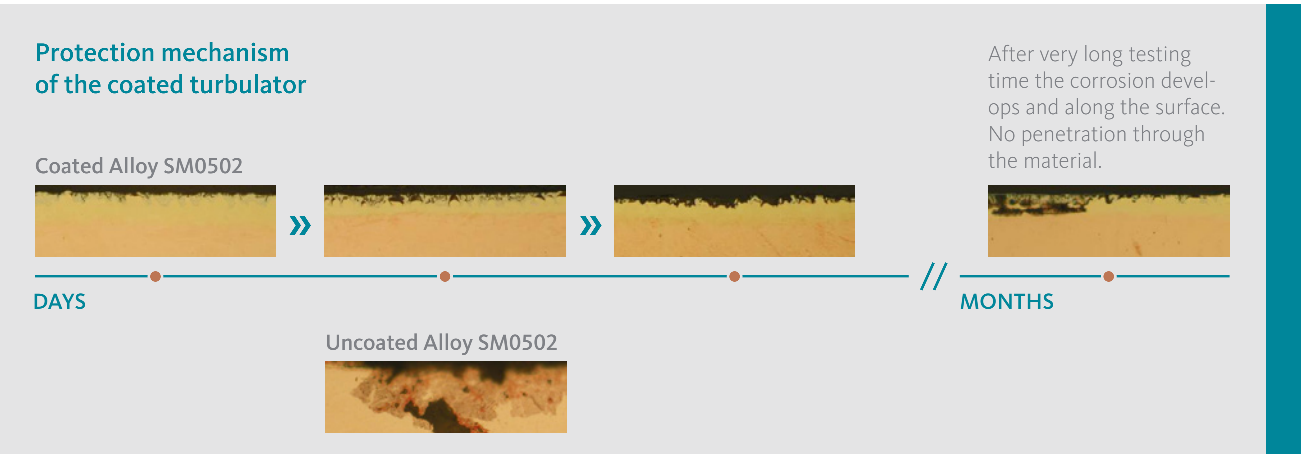

Fig. 5. These cross sectional figures illustrate the protection mechanism of the coated turbulator. The lower picture shows how corrosion penetrates through the uncoated turbulator. The series of upper pictures show that the mode of corrosion is different for the coated turbulators. Corrosion does not penetrate through but follows the surface and appears superficial.

After clarifying the key issues related to the DuraFin™-concept, Finnradiator has felt confident to start offering this solution on commercial scale. The first commercial products are already underway to mining vehicles and there have been some spin-off applications in other product segments, as well.

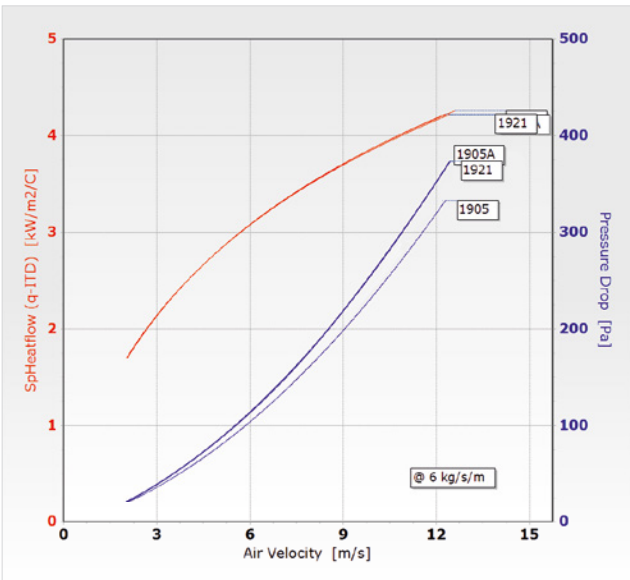

Fig. 6. Wind tunnel test results for uncoated radiator (1905) and coated radiator before (1905A) and after (1921) corrosion test. The red curves and axis show the thermal performance. The blue curves and axis show the air pressure drop. There is no practical difference between the thermal performance curves. There is an increase in the air pressure drop after the coating, because the coating occupies some cross sectional area, but no further increase after the corrosion test, indicating that there are no corrosion products.

* EGR = Exhaust Gas Recirculation

Summary

DuraFin™ heat exchangers deliver high level of reliability, cleanability and long service life that are essential in heavy duty mining applications. Together with the *Cu*proBraze® brazing technology, the benefits can be maximized in producing stronger and more corrosion resistant heat exchangers. ■

Fig. 7. Full size DuraFin™ radiator on the coating rack designed for a mining vehicle

References
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