Dr. Convey

CANADA

DEPARTMENT OF ENERGY, MINES AND RESOURCES

OTTAWA

MINES BRANCH INVESTIGATION REPORT IR 68-58

EMBRITTLEMENT OF GALVANIZED FLUE PIPE

by

J.J. SEBISTY

PHYSICAL METALLURGY DIVISION

COPY NO. 6

SEPTEMBER 12, 1968

Mines Branch Investigation Report IR 68-58

EMBRITTLEMENT OF GALVANIZED FLUE PIPE

by

J. J. Sebisty*

- - - -

SUMMARY OF RESULTS

Severe embrittlement of a galvanized flue pipe used to vent an oil-fired space-heater was primarily related to service exposure to an excessively high temperature in the neighbourhood of 1000°F (535°C). According to the relevant specifications, galvanized material should not have been used in this application.

The embrittlement characteristics of galvanized sheet at elevated temperatures, and the hazardous conditions thereby imposed in such a space-heater application, are discussed.

---

*Research Scientist, Non-Ferrous Metals Section, Physical Metallurgy Division, Mines Branch, Department of Energy, Mines and Resources, Ottawa, Canada.

INTRODUCTION

In a letter dated August 23, 1968, Mr.R.G. Whatmough, Fire Marshal, Yukon and North West Territories, requested examination of a section of a 4-in.-diameter flue pipe, which had been used to vent an oil-fired space heater (output-12,500 BTU/hr). The material was severely embrittled, presumably as a result of exposure in service to flue-gas temperatures, which, it was stated, would normally be in the range of 900°-1000°F (480°-540°C).

A request for further information revealed that the space heater had been in service for one and a half heating seasons or approximately 14 months. Although no records are available, it was stated that such embrittlement is apparently not uncommon with heaters of this type, which are used in mobile-trailer sewage-treatments units. The present case was found on routine inspection and no external fire was involved. Break-up of the pipe had occurred on dismantling. CSA tests had indicated that this class of heater could generate flue temperatures slightly above 900°C (480°C) with a maximum fuel-input rate. Whether or not the more highly refined Arctic-type Diesel fuel was used in the tests was not stated. The space heater was manufactured to CSA Standard B140.3 (Oil Burning Stoves and Water Heaters) which, in Clause 7.2.1.3, quotes an allowable maximum flue-gas temperature of 1000°F (540°C). This Standard further states in Clause 4.9.1 that, "heating surfaces, baffles and other surfaces exposed to the direct heat of the flame, or to the products of combustion, shall be constructed of sheet steel, cast iron or other suitable materials". Sheet-thickness requirements vary with heater capacity, etc., being between 18 to 22 gauge (0.0479 to 0.0299 in.).

EXAMINATION

The general appearance of the sample suggested that the pipe had been made from galvanized sheet and this was confirmed by semi-quantitative electron-probe microanalysis. This being the case, there is no doubt that embrittlement was due to long-term exposure of the galvanized material in the high-temperature range quoted. As shown by the sharp edge-breaks in Figure 1, and the fact that pieces could be readily broken away with the fingers, the material possessed no ductility whatsoever.

The industry-recommended maximum service-temperature for continuous-strip galvanized material, such as was probably used, is 555°F (290°C). Somewhat higher temperatures around 600°F (315°C) may normally be reached in flue pipes of typical, residential oil-heating equipment, and this could be expected to cause some deterioration of the galvanized coating, and in the mechanical properties of the steel substrate. However, the degree of deterioration is apparently not so severe in this limiting temperature region as to detract from useful long-service life of galvanized sheet in such an application.

Still higher temperatures would be much more detrimental, as has been confirmed in recent investigations made at the Mines Branch(1). For example, it was found that air-atmosphere heating of 24-gauge (0.025-in.) commercial galvanized strip reduced the elongation to about 5%, from the original 32%, after 84 days heating at 635°F(335°C). Zero elongation was obtained after 24 days at 690°F (365°C).

For record and reference purposes, metallographic examination of pieces from the sample was made, and Figures 2 and 3 illustrate typical cross-section microstructures. In Figure 2, the heat-affected coating is seen to consist of characteristic iron-zinc-alloy phase layers near the steel base and a thick, heavily oxidized and pitted outer layer. Intergranular penetration of the steel base by continuous chains of intermetallic compound particles was well defined near the steel surface. This tapered off in a characteristic manner farther down in the steel into a scattered distribution of individual particles. These were also located intergranularly as apparent on a heavily etched surface. The compound distribution in the steel base is somewhat better illustrated in Figure 3.

Deeply penetrating intergranular cracks were also found in the pieces examined. The relatively wide separations in Figure 2 appeared to be filled with oxidation products and, therefore, must have formed in service. The finer hair-line crack in Figure 3, on the other hand, was most probably formed when this particular piece was broken off for metallographic examination.

Apart from some variations in the size, distribution and depth of penetration of compound particles, much the same deterioration effects as described above have been observed in the work referred to earlier(1), and, in other recent Mines Branch tests. For example, 24-gauge (0.025-in.) galvanized strip heated for 10 days in air at 1000°F (540°C) showed a

---

(1) J.J. Sebisty - "Continuous-Strip Galvanized Coatings at Elevated Temperatures" - Electrochemical Technology, 6(5), (1968).

larger compound-particle size as in Figure 4. The particles were again nucleated intergranularly but there was no distinct link-up of the individual particles. As a matter of interest, the material still retained some ductility and required several bends back and forth through 180° in a vice before breaking. In the case of the test quoted previously, i.e., heating of galvanized strip for 84 days at 635°F (335°C), a typical microstructure is reproduced in Figure 5. Particular attention is drawn to the nature and extent of intergranular penetration of the steel, which was confined to a band a few grain-layers deep.

These dissimilarities in behaviour are not unexpected and, in fact, emphasize the temperature-time dependency of the diffusion-controlled embrittlement mechanism in galvanized material. Thus, the finer compound-particle size in the pipe sample suggests that the service exposure temperature was somewhere near, but below, 1000°F (540°C). The actual level is indeterminate but was most certainly excessively high and, as noted earlier, was the primary cause of the embrittlement failure.

In this type of application, it is clear that such service use of galvanized sheet can lead to a hazardous, unsafe condition. It is not inconceivable that some form of impact or vibration could cause cracking or catastrophic break-up of the embrittled flue in place, with consequent emission of combustion gases and/or threat of fire. The use of galvanized materials in such high-temperature conditions should therefore be avoided.

In this connection, it is of interest to refer again to CSA Standard B140.3. The manufacturer or installer of the space-heater may have considered the galvanized sheet used for the flue to fall into the category of either "sheet steel" or "other suitable materials", quoted in Clause 4.9.1. However, this interpretation is otherwise invalid since Clause 4.9.3 states that the maximum operating temperatures for heating surfaces, etc., must conform to CSA Standard 140.0. In Table 4 of this Standard, the permissible maximum for galvanized steel is 600°F (315°C) for normal space-heater operation. Thus, in view of the allowable flue-temperature maximum of 1000°F (540°C), the use of galvanized material for the flue pipe was clearly contrary to these Standards.

CONCLUSIONS

Embrittlement of the galvanized space-heater flue pipe submitted was primarily caused by long-term service exposure to an excessively high temperature in the neighbourhood of 1000°F (540°C).

Galvanized steel should not be used at such temperatures and the present instance was contrary to the requirements of the relevant Standards.

JJS/sg

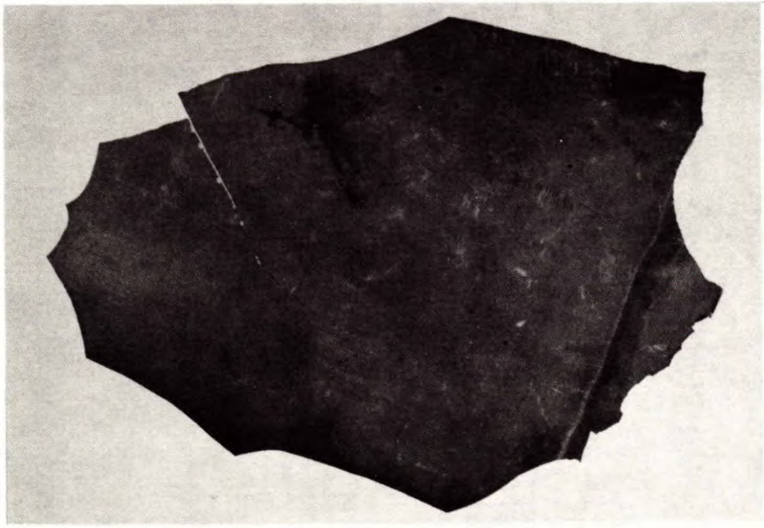

Figure 1. Photograph of embrittled flue-pipe sample showing sharp edge-breaks, X1.

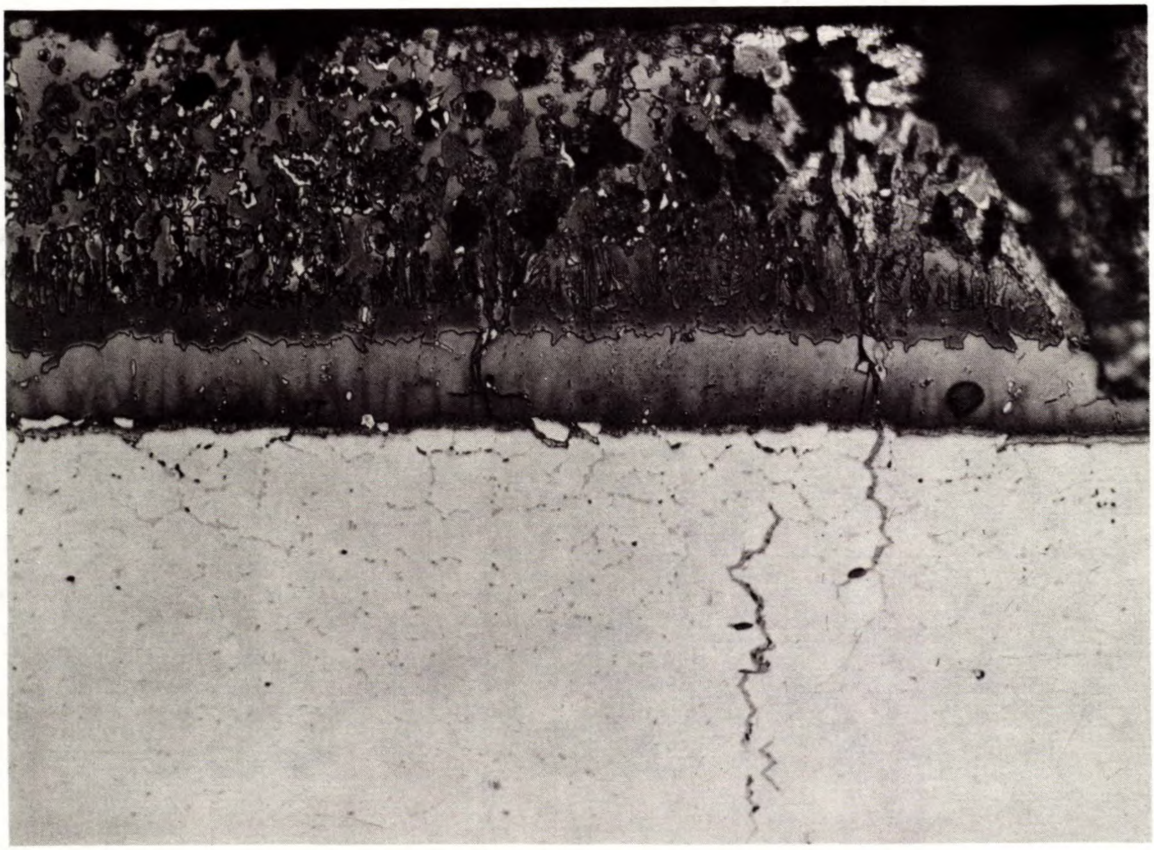

Figure 2. Typical cross-section microstructure illustrating coating features and intergranular penetration of steel substrate. Picral etch, X500.

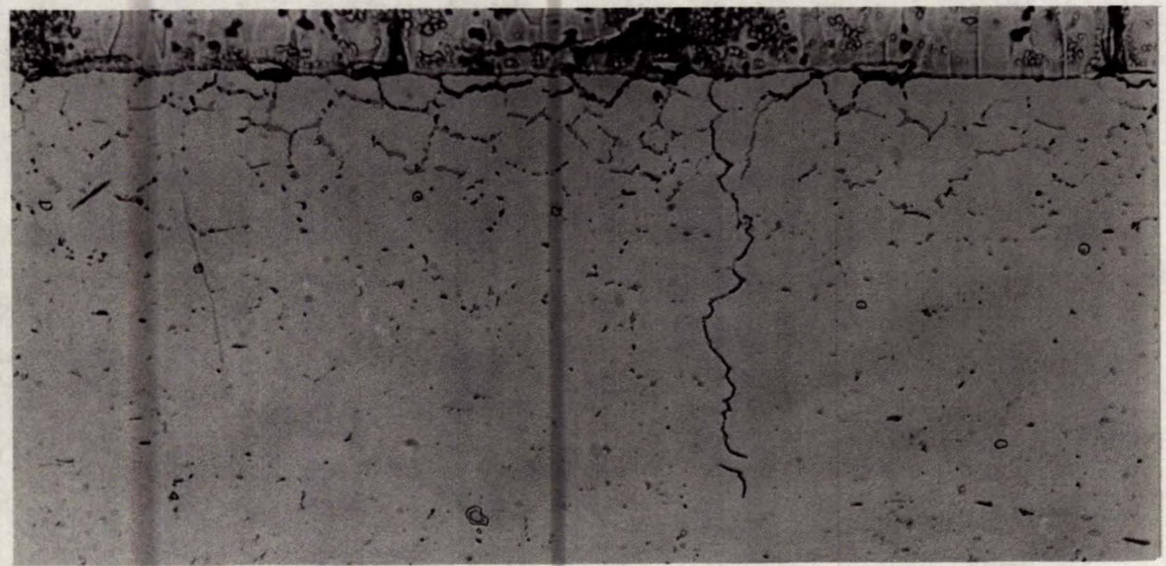

Figure 3. Intermetallic-compound penetration of steel substrate highlighted by different etching treatment. Nital etch, X500.

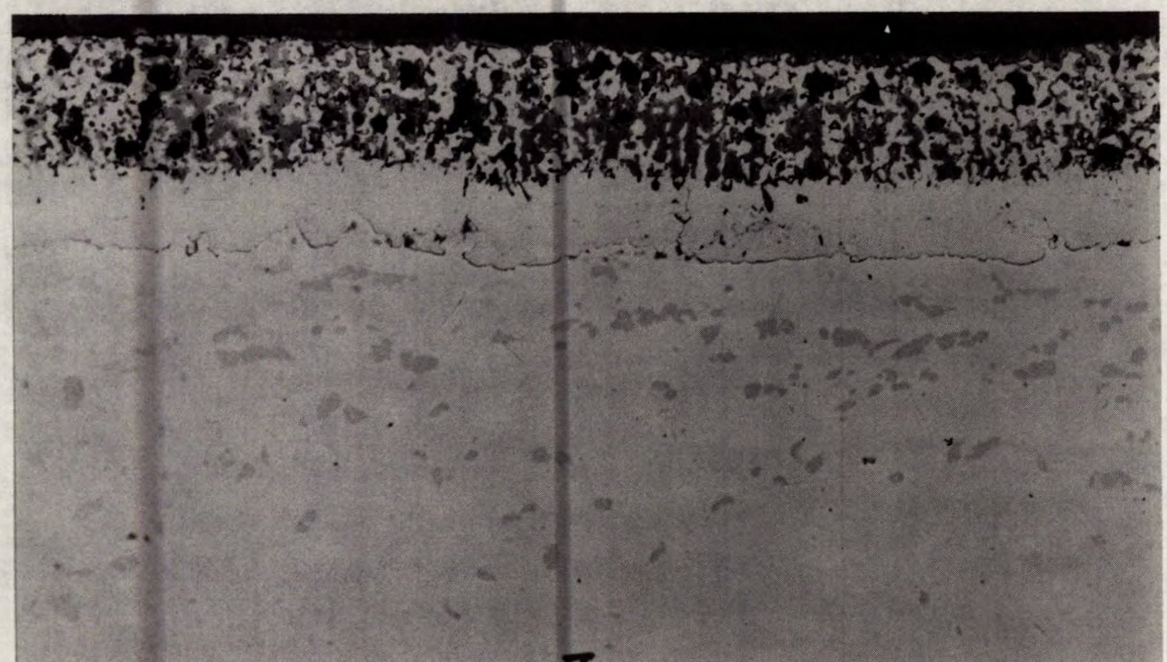

Figure 4. Microstructure of 24-gauge (0.025-in.) commercial galvanized strip heated in air for 10 days at 1000°F (540°C). Unetched, X500.

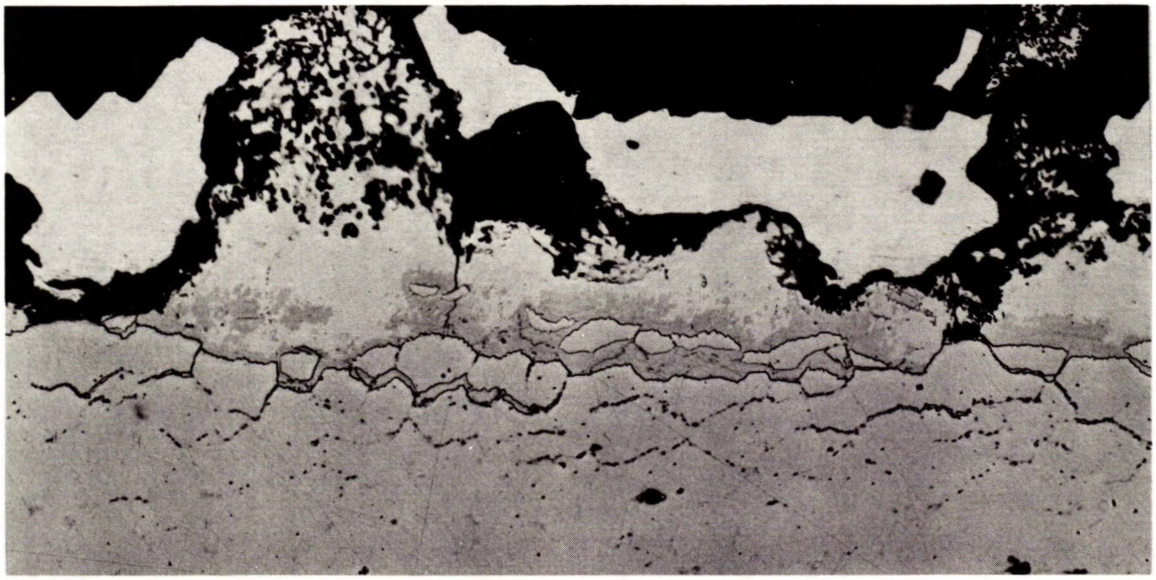

Figure 5. Microstructure of 24-gauge (0.025-in.) commercial galvanized strip heated in air for 84 days at 635°F (335°C). Nitramyl etch, X500.