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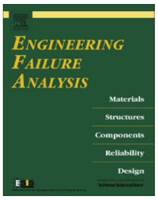

Effect of coking in massive failure of tubes in an ethylene cracking furnace

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ABSTRACT

The causes and characteristics of the massive failure of the radiant coil tubes in an ethylene cracking furnace, which failed during an emergency non-programmed stop, are investigated. The failed tubes had been in service for about three and a half years, while lifetime had been estimated in five years. Tensile testing showed severe in-service degradation of material mechanical properties. Longitudinal cracks on failed tubes are brittle and originate in the inner side of the tubes wall. All failed tubes display a thick layer of coke adhered to the inner wall. This coke comes easily broken by bending or tension stresses, but sustains compression.

The origins of loads which lead to the fracture were replicated; cracks were lab-induced by longitudinal cutting and resulting openings measured. Mechanical modeling allowed concluding that loads that led to failures were due to differences between thermal expansion coefficients of tube alloy and the coke growth within them. When the furnace was cooled down, thermal contraction of tube metal was restricted by the thick coke layer. This layer grew in service in the pressure expanded tubes.

The failures were due to a combination of circumferential loads induced by coke during fast cooling and low strength of tube material. Recommendations include monitoring coke thickness and comparing with critical thickness for tube rupture in case of an emergency stop. This way, operators will have a parameter useful to schedule decoke processes.

1. Introduction

The causes and characteristics of the massive failure of the radiant coil tubes in an ethylene cracking furnace, which failed during an emergency non-programmed stop, are investigated (see Fig. 1) [1]. This analysis leads to establish material, manufacturing and assembly quality on one hand, and to determine operative conditions that contributed to the failure, on the other. As there are similar components operating in the same plant as well as in other plants, this study aims to identify failure mechanism/s, to determine the causes that created the conditions for this mechanism to cause premature failure of the material, to establish the likeliness for this failure to happen again on similar components and to establish possible mitigation measures.

The furnace has twenty similar coil assemblies. The tubes have an inner diameter of 102 mm, and 10 mm thickness. Tube length varies depending on its position in the assembly. Tube specification agrees with a Cr–Ni centrifugal casting with additions of Nb, Ti, Si [2]. Operating temperature is 850 °C, outlet pressure of the cracked gas is 0.5 barg.

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The failed tubes had been in service for about 3.5 years, while the estimated lifetime for these tubes is about five years. Since the start up, a periodical decoke process is planned every 90 days, depending on the "Nozzle Factor", among other influence factors [3]. This guarantees the cracking process not to be altered by the presence of the coke inside the tubes. The coke gets deposited on the inner surface of the tubes, raising flow rate and decreasing thermal transfer as thickness grows.

During an emergency stop the furnace was taken out of service, letting it cool down from service to room temperatures. The day after, plant personnel realized that all the radiant coils in the furnace suffered cracking, leaving the furnace completely useless (Fig. 1).

This is not the first failure in this kind of equipment occurring within this petrochemical company. Cracking in three convection tubes [4] were analyzed some years ago; in that case the leaks were located in the surroundings of the pressure measurement nozzle. The results suggested that cracks initiate at the inner surface and propagate in an intergranular way. Microstructures were compared in the inner surface and in mid-section of the thickness. The results indicated that material suffered carburization. A failure of apparently similar characteristics occurred in another plant of the same type, during a non-programmed stop of the furnace. In that case, the failed tubes were brand new.

Heat resistant alloys have widespread uses in the petrochemical industry. These alloys have replaced the traditional nickel based superalloys and have equivalent properties under creep conditions, with excellent resistances to high temperature oxidation [5]. In most cases, these complex alloys are used in their as-cast condition but, during service, ageing and phase transformations occur. The typical microstructure of as-cast alloys is an austenite matrix with intergranular eutectic-like primary chromium-rich carbides (M7C3 and/or M23C6 types) and niobium carbides (MC type). During service at temperatures of 850–1050 °C, all the primary chromium carbides eventually transform into M23C6; intragranular secondary M23C6 carbides also precipitate within the austenite grains, contributing to strength and creep resistance [6,7].

The operation range of these alloys is 533–1150 °C. High heat transfer coefficient, mechanical strength at elevated temperatures, creep resistance, microstructural stability, carburization resistance, oxidation resistance, and economics are considered for the selection of these materials for equipment structures [8]. The demand for higher creep strengths at higher temperatures, with ever diminishing wall or section thickness, has been the major driving force behind these material developments [9].

Both microstructure and operational conditions are the main parameters which affect the fracture of these alloys [10]. Failure mechanisms generally encountered are fatigue, stress corrosion cracking and ductile fracture [11,12].

Creep resistant alloys also contain a significant quantity of carbon, required for solid solution strengthening as well as carbide formation. Of further importance is the secondary carbide formation, where carbides precipitate during operation at high temperatures. Precipitation takes place at operating temperature. In general, they have an austenitic (γ-phase) matrix and contain a wide variety of secondary phases. The most common second phases are metal carbides (MC, M23C6, M6C, and M7C3) and γ', the ordered face-centered cubic strengthening phase [Ni3(Al, Ti)] found in age-hardenable Fe–Ni–Cr and nickel-base superalloys.

Exposure to an excessively high temperature could have three detrimental effects [13]. First, creep can lead to the accelerated formation of grain boundary voids; creep deformation can also lead to cracking of the protective oxide scale causing an accelerated carburization attack. Secondly, high temperature accelerates the rate of carburization attack. The effect of creep is compounded by the presence of a continuous network of grain boundary carbides [14]. Thirdly, the changes in mechanical properties are connected with the evolution of intermetallic phases and other intermetallic compounds arising in service [15].

The carburization behavior of the tubes used under the conditions of petrochemical cracking processes depends in a first line on the temperature. Up to 1000 °C carbon pickup is low, but above 1050 °C heavy carbon pickup and increasing carburization depth must be counted with. This temperature dependence is due to the fact that at 1050 °C equilibrium is attained between chromium oxide and carbide, so that the oxide is no longer stable and the original protective effect of the oxide

Fig. 1. Failed tubes within the furnace after emergency stop.