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CASE HISTORY—PEER-REVIEWED

Grade P110 Tubing Shredded by Downhole Detonation

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Abstract A failure analysis was performed on a length of API 5CT Grade P110 tubing that failed while being used in a drilling operation. Approximately 10 feet of the tubing was shredded by axial slits, and there were collapsed zones above and below the failure. The slits were at 45° to the tubing surface and showed very fine microvoid coalescence. Metallographic examination showed that the slits had formed along adiabatic shear bands. The presence of adiabatic shear bands indicated an extremely high strain rate. That, combined with the orientation of the slits, indicated that the failure was caused by a detonation of gasses in the annulus surrounding the tubing. Well operations responsible for the detonation will be briefly addressed.

Keywords Grade P110 tubing · Detonation · Intermittent collapse

Introduction

While drilling using foamed air as the drilling fluid with a pneumatic motor to rotate the bit, the rig crew received an indication of a failure downhole. A small amount of hydrocarbons had previously been noted in the returns, which destabilized the foam. When the tubing was pulled out of the hole, a 10-foot span of the 2–7/8-inch O. D., 7.90-ppf API 5CT Grade P110 EUE tubing was discovered to have been shredded by a large number of axial slits, as shown in Fig. 1. The shredded tubing was approximately 15 lengths above the bottomhole assembly.

The slits were axial, but were oriented at approximately 45° to the outside surface of the tubing, as shown in the cross section of Fig. 2.

Approximately 10 feet of tubing above and below the shredded portion was collapsed, and there was an interval in the middle of each collapsed zone where the tubing retained a round profile, as shown in Fig. 3.

The upper collapsed zone was separated from the shredded portion by an upset connection, which remained visibly intact, indicating that the collapse damage had occurred on two separate lengths of tubing.

Laboratory Examination and Testing

Because the collapse did not extend to the lower end of the shredded tubing, a portion of apparently intact tubing was available for testing. Tension test results, wall thickness, and diameter were satisfactory for the specified size, weight, and grade of tubing. No manufacturing defects were identified.

Scanning Electron Microscopy

A portion of the fracture surface created by one of the slits, shown in Fig. 4, was examined using a scanning electron microscope. Although much of the surface was covered with an adherent oxide, the exposed portions of the fracture were very flat, but showed a fine microvoid coalescence fracture, as shown in Fig. 5.

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Fig. 1 A portion of the shredded tubing, after cleaning. Scale is in inches

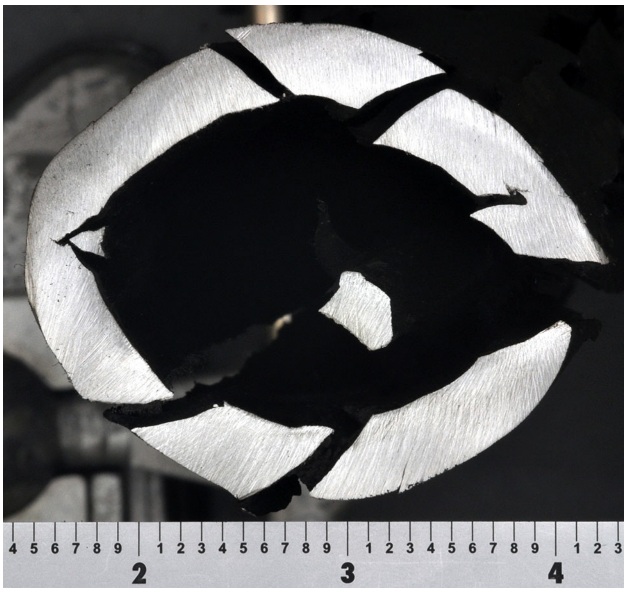

Fig. 2 A cross section of the shredded portion of the tubing. Scale is in inches

Fig. 3 Intermittent collapse

Metallography

A metallographic specimen, shown in Fig. 6, was prepared from a transverse section of a strip created by two of the slits. The specimen was criss-crossed with slip bands at 45° to the surface, parallel and perpendicular to the orientation of the slits. The slip bands were associated with surface relief, but did not necessarily extend through-wall. At higher magnification, it was evident that the fractures occurred along highly localized shear bands that were

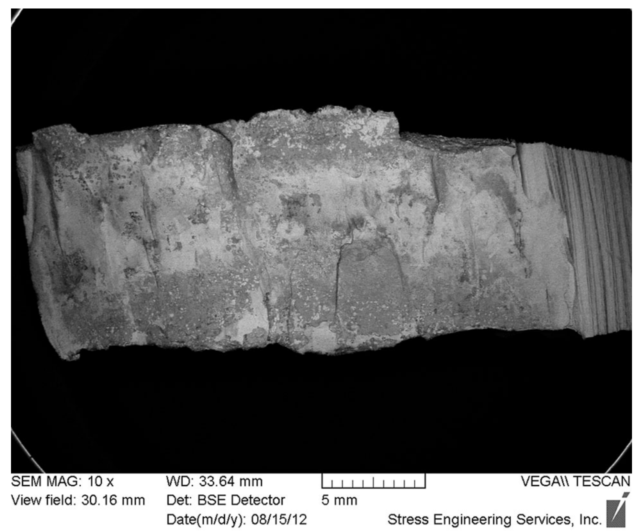

Fig. 4 SEM backscattered electron image of a fracture surface

characteristic of adiabatic shear bands, as shown in Fig. 7 (For a comparable image of an adiabatic shear band in carbon steel, see Wright [1]). Apart from the deformation associated with the shear bands, the microstructure was uniform tempered martensite, typical for API 5CT Grade P110 tubing.

Discussion

The characteristics of the failure indicated it was caused by a detonation in the annulus surrounding the tubing. Specifically, (1) the multitude of axial slits indicated a high-energy failure, (2) the presence of adiabatic shear bands indicated high strain rates [2], (3) the collapse damage indicated extremely high pressures in the annulus (differential greater than 19,000 psi, based on the rated collapse resistance of the tubing [3]), (4) the intermittent and interrupted nature of the collapse damage above and below the shredded portion was consistent with a short-duration pressure wave, and (5) the 45° angle of the slits closely resembled damage created in laboratory settings by explosives wrapped around a hollow cylinder [4].

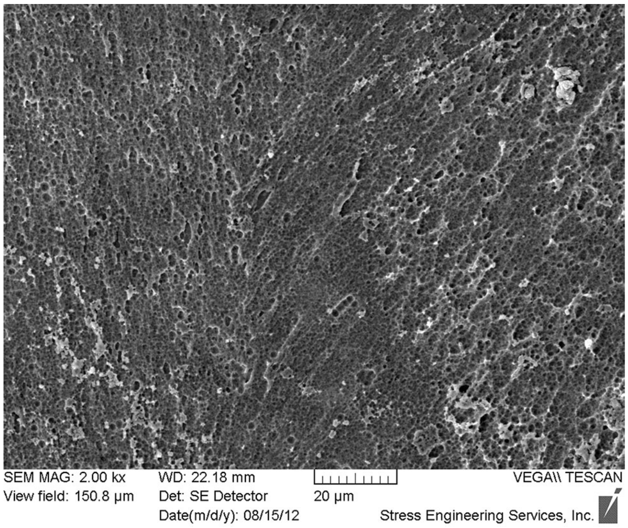

Fig. 5 SEM secondary electron image, showing fine microvoid coalescence fracture. Original magnification: ×2000

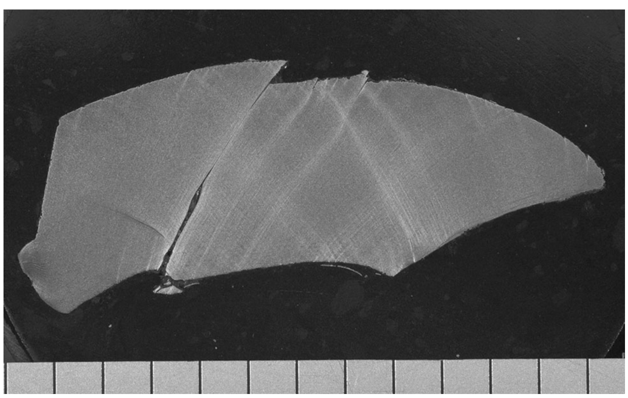

Fig. 6 Metallographic specimen, showing shear bands. Nital etch. Scale increments: 0.1 inch

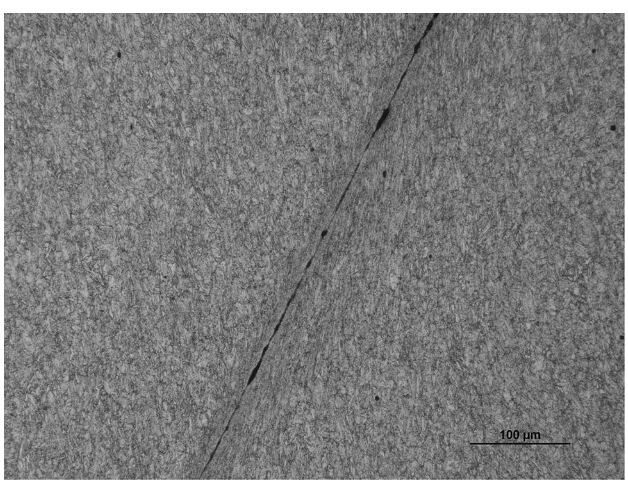

Fig. 7 Fracture along adiabatic shear band. Nital etch

The features of the failure indicated that the impulsive loading responsible for the failure was in the annulus surrounding the tubing, where air and hydrocarbons were mixed, rather than inside the tubing, which contained only compressed air. The collapse damage was clearly caused by excessive pressure in the annulus, and the 45° orientation of the axial fractures indicated that they were generated by shear stresses from circumferential compression of the tubing. Under less dynamic loading conditions, excessive external pressure will cause an instability and collapse. However, the high strain rate from the impulsive loading caused the strain in the region closest to the detonation to be localized in adiabatic shear bands. As a result, that portion of the tubing shredded rather than collapsed.

The appearance of the collapse damage above and below the shredded portion of the tubing also suggested impulsive loading. In upset tubing, a collapse failure caused by excessive external pressure typically initiates at a single point and propagates rapidly in both directions until it arrests at the thicker upsets at each end, or until the deformation causes the tubing to leak, allowing the pressure to equalize. If the tubing is ductile enough that it flattens without rupturing, additional lengths of tubing above and below it may collapse as well. Because a collapse propagates so rapidly; however, it is unusual to have two separate collapsed zones in a single length of tubing, as was observed in both the damaged length and the length above it. The unusual appearance of the collapse damage thus suggested it was caused by a pressure wave rather than by sustained external pressure.

A common hazard associated with air drilling in the presence of hydrocarbons is a downhole fire [5], but downhole fires generate extreme heat and result in very ductile torsional failures with associated microstructural changes. This failure showed a very different appearance: there was little evidence of torsional yielding, and the microstructure showed no evidence of the overheating that is typical of downhole fires. The microstructural evidence of impulsive loading indicated the failure was caused by a detonation, not a fire.

Drilling with compressed air continues to enjoy vast popularity. It is often the application of choice in dry, hard rock because the drilling fluid medium is inexpensive and, compared to water or weighted drilling mud, respectable rates of penetration can be achieved. In terms of economic considerations with respect to drilling fluid expenditures, air drilling has virtually no equal. However, air drilling is not without its impediments, not the least of which is its reactivity with hydrocarbons.

When atmospheric air is compressed, the local temperature increases because of the compression of the air molecules in a confined space as illustrated in Fig. 8.

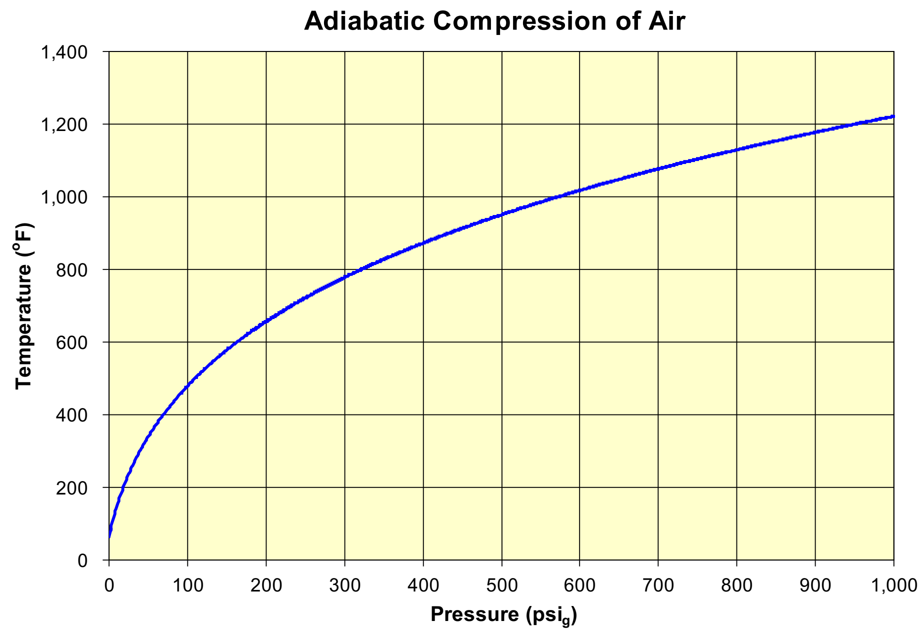

Fig. 8 Temperature increase due to adiabatic compression of air

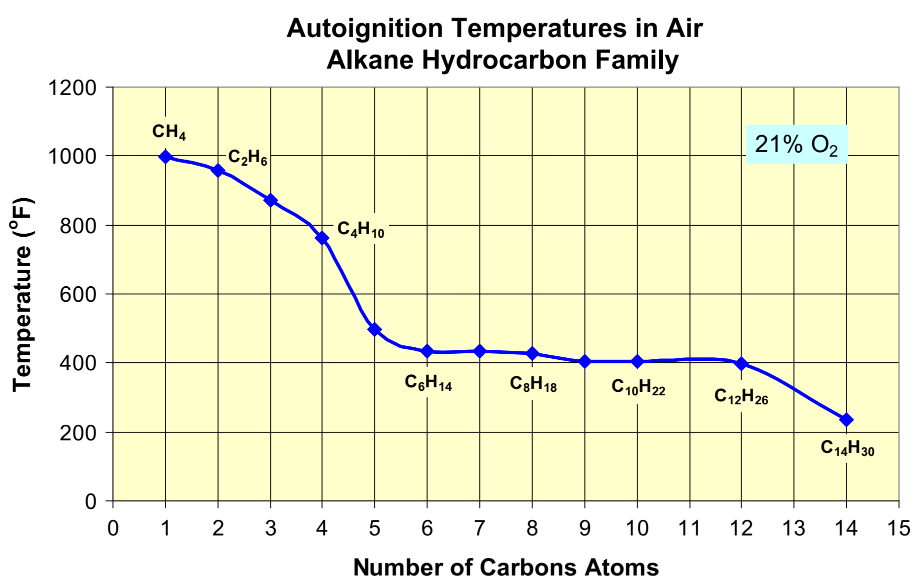

Fig. 9 Autoignition temperatures of alkane hydrocarbons declines with chain length

Additionally, the partial pressure of oxygen increases as well.

Figure 9 illustrates the autoignition temperatures for aliphatic hydrocarbons commonly produced. The ignition temperature tends to decrease with the number of carbons in the chain. An increase in pressure typically reduces the spontaneous ignition temperature.

A typical mechanism proceeds as follows: compressed air exits the bit or downhole hammer, a productive pay is exposed usually producing condensate, a mud ring forms uphole creating an annular packoff between the drill pipe and the protective casing. The air compresses in that space below the annular packoff increasing the partial pressure of oxygen and supplementing the heat already in the confined space through adiabatic compression. Add fuel from the condensate, and a possible ignition source such as a friction spark from the drill bit or downhole hammer—the result is a downhole detonation, very similar to that created in a diesel engine.

A superposition of the adiabatic heating of air and the autoignition temperature of alkanes in Fig. 10 illustrates why downhole detonations seem to occur more frequently in the presence of condensates, also known as "wet" gas. The higher molecular weight chains require less

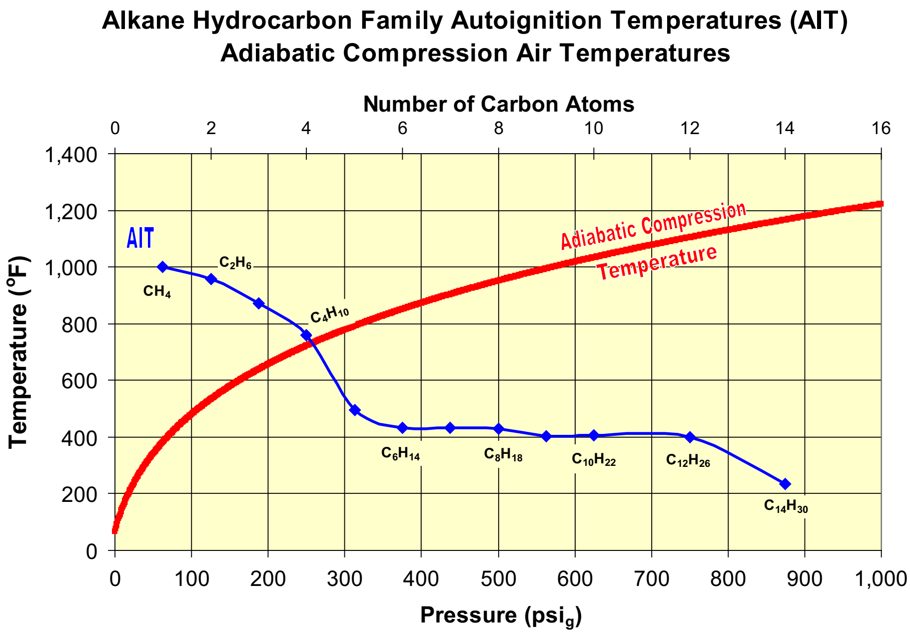

Fig. 10 Autoignition temperatures of alkane hydrocarbons superimposed with temperature change due to adiabatic compression of air

temperature, and correspondingly less compression when mixed with air, in order to detonate.

The resulting detonation can be so violent and intense that it collapses (actually flattens) and twists drilling tubulars. Often times, there is little need to run a junk basket after a downhole detonation because the bottomhole assembly and bit disintegrate downhole.

Downhole fires and detonations can be effectively prevented by using compressed nitrogen rather than compressed air as the drilling fluid when entering hydrocarbon zones.

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