Pergamon

Engineering Failure Analysis, Vol. 5, No. 2, pp. 143–147, 1998

Printed in Great Britain
1350–6307/98 $19.00 + 0.00

PII: S1350–6307(98)00011–9

CREEP FAILURE OF A SPRAY DRIER

P. CARTER

Advanced Engineering and Testing Services, CSIR, Private Bag X28, Auckland Park 2006,
Republic of South Africa

(*Received* 3 *February* 1998)

Abstract—NDT, design calculations and metallurgical analysis were performed on specimens from a collapsed spray drier. Failure modes initially regarded as possible were: corrosion leading to reduced sections and loss of strength, fatigue and fracture, and creep. The calculations pointed to creep, and no positive metallurgical or physical evidence was discovered to support any of the hypotheses. However, the compression stresses implied that creep deformation could have occurred without inducing discernible creep damage. It was concluded that buckling and collapse of the structure was due to excessive creep deformation. © 1998 Elsevier Science Ltd. All rights reserved.

Keywords: Creep, buckling, overheating, process-plant failure, stress concentrations.

1. BACKGROUND

A spray drier which had been in service for nearly 20 years at the Western Platinum Mine metallurgical plant, collapsed on a quiet day while operating normally. The spray drier consisted of a cylindrical shell some 15 m in height and 5.5 m in diameter, supported vertically on four 5 m steel columns. Combustion gas controlled at 550°C from a chain-grate stoker entered an annular chamber encircling the base of the shell. The gas entered the cylinder from a number of ports on the inside of the annulus; it then travelled up the cylinder, drawn by an induced draught fan, in order to dry a slurry falling from the top of the drier in a counterflow arrangement. The dry product was collected from a cone at the bottom of the cylinder. The drier was lagged and clad from top to bottom to conserve energy.

Figures 1–3 show views of the collapsed drier. Braced columns, the lagged and clad annulus and shell, and the bottom cone, are all visible.

These figures show the remarkable nature of the collapse, with the column and cone moving down axisymmetrically until the weight was supported by the cone on the ground.

The aim of the investigation was to explain the failure and to make recommendations to ensure that it was not repeated on the two remaining driers, which had seen some 7 years' service.

2. INSPECTION

Ultrasonic NDT was performed on columns and some areas of the annulus and shell on the remaining two driers. Attempts to measure the temperature of the insulated skin of the annulus of these driers were made with limited success. A probe inserted into the lagging against the outer annulus shell indicated temperatures in the range 330°C–360°C. This was felt to be unrealistic, due to the fact that the plate had gas at 550°C on one side and 250 mm of fibre glass lagging on the other side. Where possible, thickness checks were made on the failed drier, and sections of shells and columns were removed for metallurgical analysis.

These investigations all gave negative results, that is, no significant corrosion was observed, and both columns and shell material were consistent with Grade 430 mild steel without any deterioration in properties. No evidence of fatigue and fracture was found and in particular, no physical evidence of creep damage was found.

Fig. 1. View of base of collapsed drier.

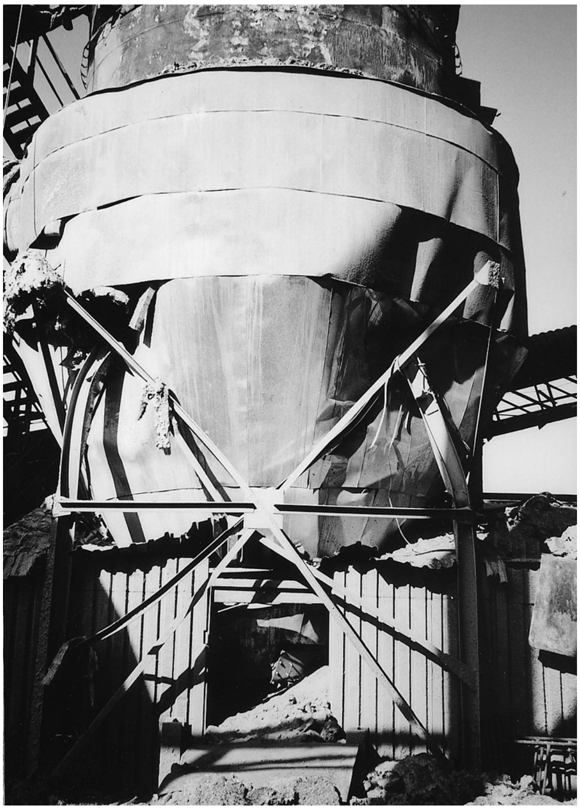

Fig. 2. View of base of collapsed drier.

There was clear evidence of a localised buckling deformation in columns and shells in the region of the welded column-shell joint. This was distinguishable from the damage associated with a collapse event itself.

Fig. 3. View of buckled column.

3. STRESS ANALYSIS AND ASSESSMENT

The approach in this section is to compare stresses at critical points in the structure with allowable and failure stresses, inferred from BS 5500 [1], the design code for pressure vessels, which has high temperature materials data.

Figure 4 is a summary of design and failure data for Grade 43 steel, based on a service life of 150,000 hours or 17 years. Failure data for creep rupture is inferred from design data using the quoted safety factor of 1.3.

Further, extrapolation for temperatures >480°C is necessary. There is a justification for using

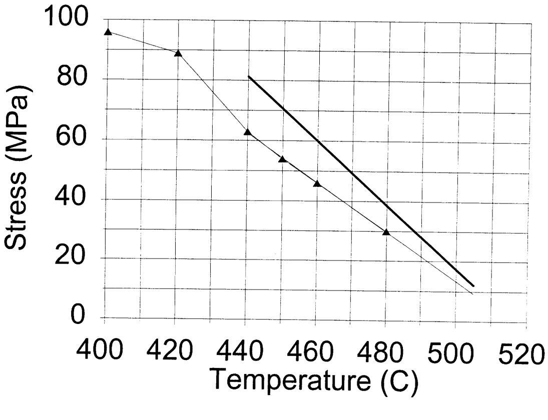

Fig. 4. BS 5500 stress-rupture data for Grade 430 steel.

tensile creep rupture design and failure data for this case. Although creep-rupture does not occur in compression, it is expected that strain rates will be similar for tension and compression.

Strain limits associated with allowable stresses are in the region of 1%. Significantly more strain will accumulate if stresses approach the rupture limit, so using design failure stresses in compression to assure strain limits is justifiable.

Stress analyses were performed on two details of the drier:

(i) Axisymmetric gas annular duct and main shell connection (Fig. 5, SCF1).
(ii) Shell-column connection (Fig. 6, SCF2).

The results in each case are expressed as a stress concentration factor (SCF) based on the average loading on the shell, estimated as 45 tonnes. The results are summarised in Table 1.

These calculations are based on a linear elastic material model. The effect of creep is to redistribute stresses. A beam in bending can redistribute elastic stresses so that for a high creep exponent ($\gtrsim 6$) the maximum stress is about 67% of the maximum elastic stress. The gas duct SCF of 8.9 is associated with bending, so under creep conditions, a value of 6 is appropriate.

The elastic stress distribution for the geometry in Fig. 6 would have the characteristics of a notch, since the idealised structure is supported at a point.

An estimate of the creep stress concentration factor can be obtained using a Neuber calculation described in the ASME III Code Case N47 [2]. Here, the product of stress and strain using the inelastic isochronous stress–strain curve must be the same as the product of elastic stress and strain, including stress concentration.

The BS 5500 [1] data may be used to infer a stress–strain curve such that a stress of 18 MPa at 500°C causes a strain of 1% in 1.5×10^5 h. Assuming a high exponent (6, say), this approach produces a creep stress concentration of 3, compared with the elastic value of 5.4. Thus for creep conditions, the maximum stress in the structure is 22 MPa, compared with 32 MPa for elastic conditions.

Examining the BS 5500 [1] data in Fig. 4, it is clear that for design purposes a maximum metal temperature of 480°C would be allowed for the above stresses. To explain the failure, a temperature between 490°C and 500°C is required.

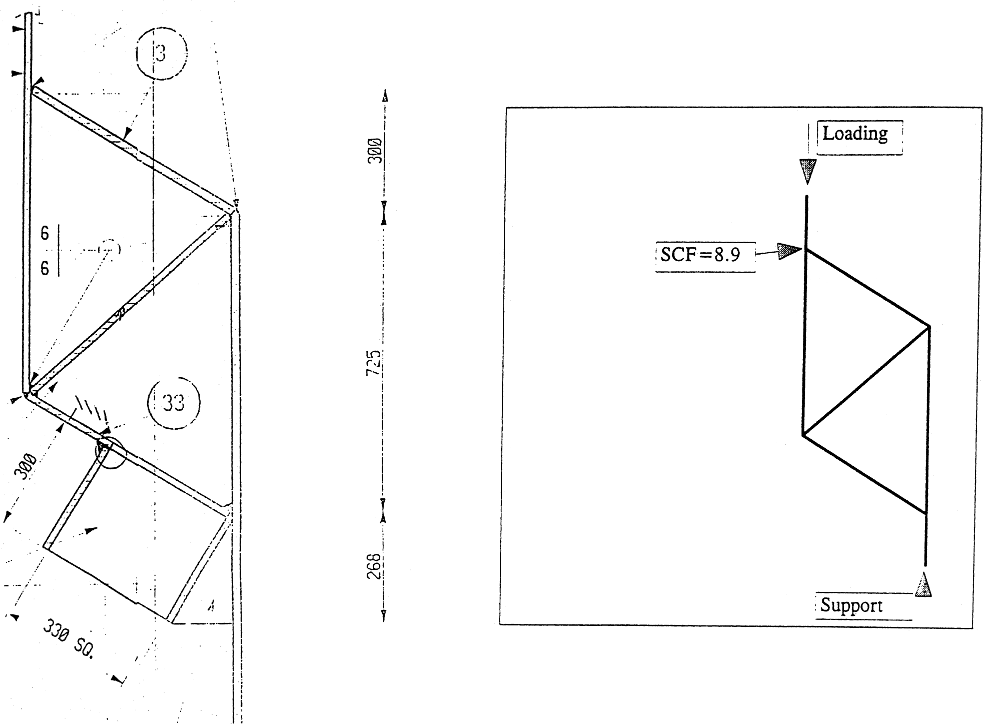

Fig. 5. Gas duct cross-section.

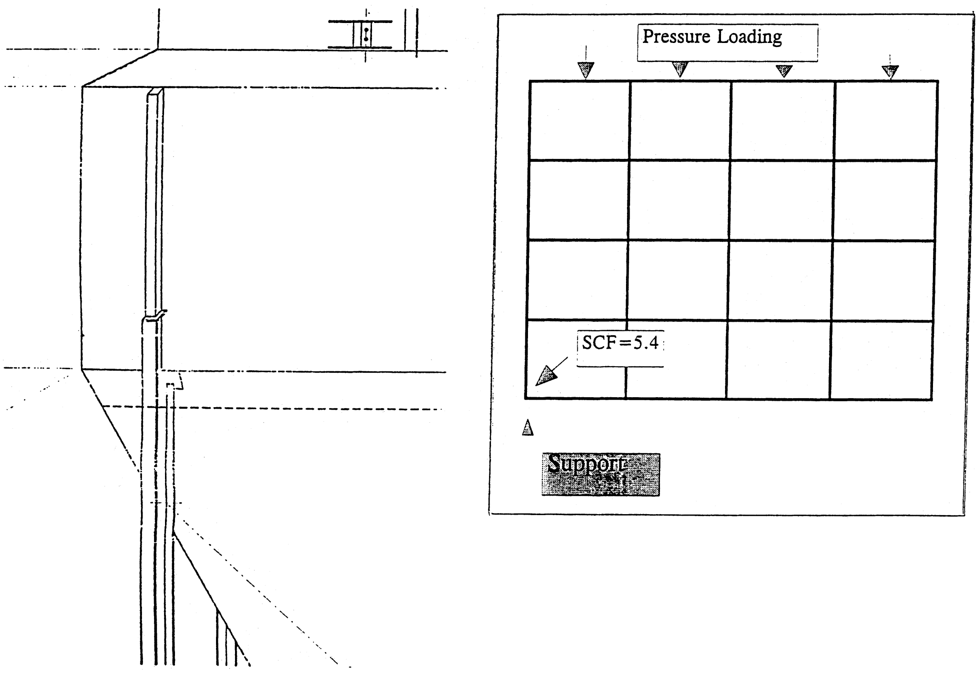

Fig. 6. Column-shell detail.

Table 1. Stresses and allowable stresses (500°C)

Region	Nominal stress (MPa)	SCF (elastic)	SCF (creep)	Stress (MPa)	Allowable (MPa)	Failure (MPa)
Gas duct	3.6	8.9	6.0	22	13	17
Column-shell	3.6	5.4	3.0	11	13	17

The values of stress and allowable stress in this paper should not be regarded as anything other than estimates. However, they do clearly indicate the nature of this failure.

4. CONCLUSIONS

The collapse of the spray drier after 20 years in service is an unusual example of a low stress, high temperature compression creep failure.

To avoid a similar fate on other more recent (and stronger) spray driers, it was recommended that the lagging and cladding in the region of the annular gas duct and the column-shell joints, be removed.

Acknowledgements—The kind permission of the management of Lonrho Platinum Division to publish this paper is gratefully acknowledged.

REFERENCES

1. BS 5500 Specification for Unfired Fusion Welded Pressure Vessels, British Standards Institution, London.
2. ASME Boiler and Pressure Vessel Code, Code Case N47-12, ASME, New York.