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PERFORMANCE OF BULGES AFTER WELD-OVERLAY REPAIRS

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ABSTRACT

One of the commonly-used long-term bulge repair methods for coke drums is automated weld overlay. The post-repair performance of bulges in a set of operating coke drums is examined. The findings demonstrate if and how this repair method alters the trend of bulging severity in the short and long run.

INTRODUCTION

Coke drum bulging is a common type of damage that had been recognized, documented, and examined since the 1950s, [1]. Since then, numerous investigations have been performed, mostly in the last ten years, to understand the cause and assess the consequence of this failure mode, [2-12]. If not addressed, bulges typically deteriorate to the point of inducing cracks which, if not mitigated, can cause loss of containment.

The classic repair method for bulging has been to remove damaged plate either by window or can replacement. Despite the significant difficulty, expense, and disruption of this repair approach, some users have reported that such repairs experience cracks within two to five years.

The advent of automated welding machines that are capable of depositing large amounts of filler material with reasonable consistency and quality has enabled industry to strengthen instead of replace bulged areas. Laboratory testing and industry experience suggest that properly designed and implemented weld overlay repairs can be effective in mitigating this failure mode and extending the life of bulged coke drums, [13-20].

EQUIPMENT DESCRIPTION

The subject of this study is a set of eight 18 year old coke drums that are 29 feet in diameter and have a variable shell thickness between 1 and 1.5 inches. The shell is made out of 1 ¼ Cr - ½ Mo base metal with stainless steel clad.

During their life span, they were operated at a total cycle time that varied between 48 hours to 28 hours. Despite the fact that they were fabricated using excellent quality and standards, these drums developed excessive bulges after seven years in service. Several drums were repaired using automated weld overlay in stages starting after ten years in service.

A representative bulging pattern in these drums is shown using the three-dimensional radius map and side views in Figure 1. Using the bulge classification of [21], the map shows a relatively mild "uniform growth" below fill level, one or two "band growth" areas, and numerous "local bulges".

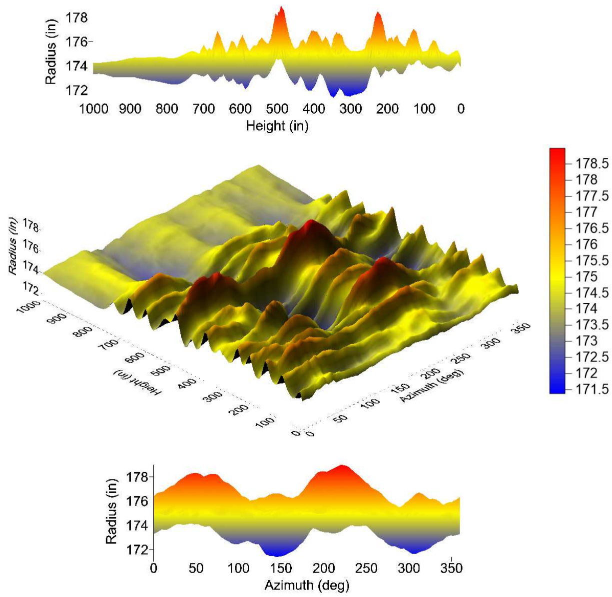

Fig. 1 A Representative Bulging Pattern

The severity of bulges in these drums was assessed using the plastic strain method of [7-9] and [19-20]. Indications that exceeded the "Design" level in all drums are shown in Figure 2. In the chart, a unique symbol is used for each one of the eight drums. Azimuth is referenced to North, height is referenced to the bottom tangent line. Circumferential seam welds which are commonly associated with shell cracks are indicated using red lines.

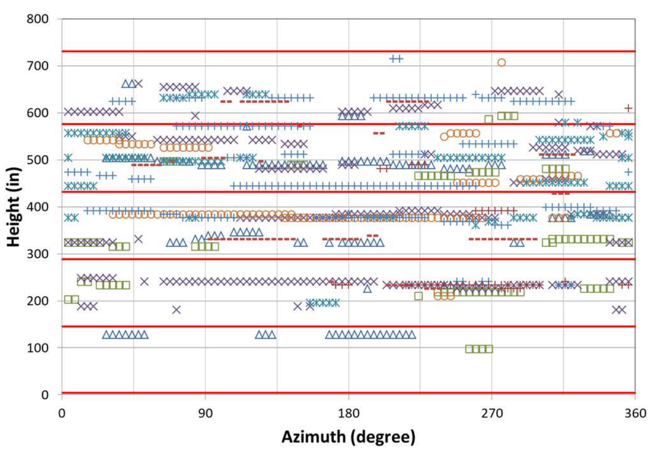

Fig. 2 A Chart of Severe Bulge Indications (each symbol represents one drum)

As the figure shows, most indications are located in middle shell courses (third and fourth from the bottom) followed by the second and fifth courses and then by the first. No indications were found above the fill level which varies at a height of approximately 787 inches (20 m). This general bulging pattern is in-line with industry experience, as reported in [22]. However, bulges in these drums were located both at and away from circumferential seam welds not only at these welds as many operators have reported in the past. This is likely due to the high fabrication standards that were used for making welds in these drums.

REPAIR APPROACH

Shortly after placing the subject set of drums in service, some of them started experiencing bulging and cracking in an unpredictable manner. After approximately ten years of service, the first through-wall crack was observed. An example of a bulge-induced crack is shown in Fig. 3.

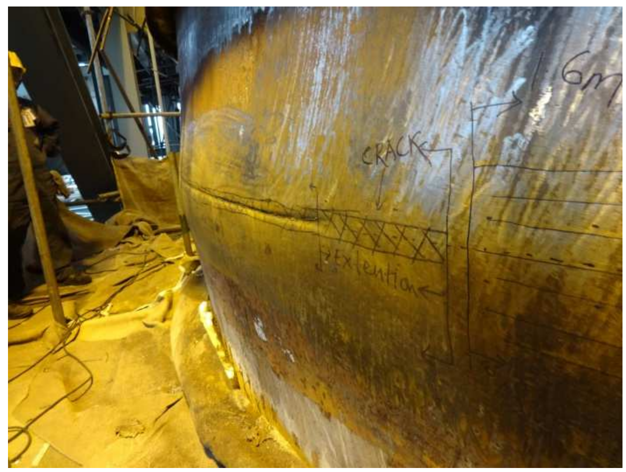

Fig. 3 Example of a Bulge-Induced Crack

Repairing bulging-induced cracks by gouging them out and rewilding is a short-lived solution. To extend the economic life of these drums and minimize unplanned shutdowns, bulging was managed in a proactive manner using a three-pronged process:

1. First, laser scanning is used to map the radius of the drum and quantify distortions. The method utilized for surveying these drums employs a two-dimensional scanner that collects measurements as it is incrementally lowered into the drum.
2. Then, laser measurements are used to perform bulging assessment to determine severity and specify repair scope (e.g. location, size, wall surface, material, thickness, perimeter details, surface treatment, etc.). The method used for assessment of these drums is based on calculation of plastic strain.
3. Specified repairs are performed using weld overlay enforcement. The method used to implement repairs in these drums employs a GMAW process with controlled-deposition temper-bead welding by automated machines. An example of a completed weld overlay surface is shown in Fig. 4.

The above methods that were chosen for managing this set of drums are not unique and the process has its advantages and disadvantages. In addition, the outcome of the process is highly dependent on the underlying technologies. For example, laser scanning methods can be susceptible to too much instrument or vibration noise to make them useful for assessment; bulging assessment methods may not necessarily correlate with bulging-induced cracks to make repairs effective; and weld overlay procedures can result in too many discontinuities and flaws to produce a durable repair. This is why the performance described in this paper may not necessarily be identical to the experience of other operators.

Fig. 4 Example of a Weld Overlay Surface

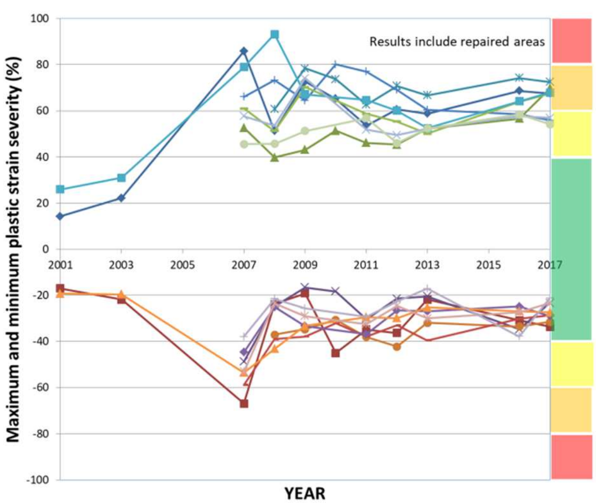

Fig. 5 History of Plastic Strain Severity in Drums

RESULTS

The history of plastic strain severity in these drums is shown in Figure 5. Maximum and minimum values in the chart represent the range of severity for all bulges in all drums including bulges that were repaired using weld overlay. The colors on the side of the chart indicate bulging severity that range from green (low) to red (high). The chart shows that after a history of successive increases in the magnitude of plastic strains, some drums demonstrated a decrease or a stabilization of severity.

Depending on results of bulging severity assessment, some drums received multiple weld overlay repairs while others did not receive any. Table 1 compares bulging severity before and after weld overlay repairs were implemented on the most severe bulges. The table also shows the total weld overlay area in each of the repaired drums.

Before-repair severity is based on laser scans obtained in 2009 for four drums and in 2010 for the other four. Most weld overlay repairs were implemented in 2010 and 2011. After-repair severity is based on laser scans of 2017. The significant scatter in magnitude of improvement of repaired drums and in the rate of deterioration of unrepaired drums is a characteristic of coke drum failures. High scatter is caused by the spatial and temporal inconsistency of thermomechanical loads that depend on random flow channel formation inside the coke bed during filling.

Table 1 Summary of Bulge Severity Change

		Maximum Plastic Strain Severity (%)			
Drum Set	**Drum**	**Before Repairs**	**After Repairs**	**Change**	**Average**
Severe bulges repaired using weld overlay	A	65.2	67.6	4%	-9%
	B	73.7	72.5	-2%	
	C	80.1	55.9	-30%	
	D	70.3	67.6	-4%	
	E	67.1	67.9	1%	
	F	74.2	57.0	-23%	
Not repaired	G	51.4	69.7	36%	21%
	H	51.2	54.1	6%	

Above data describes performance of entire drums with all their bulges. The performance of individual bulges that receive weld overlay repairs is illustrated using the history of the example in Figure 6. This representative post-weld overlay repair performance in these drums is established using three scans prior and five scans after the repair was implemented. Like most such repairs in this set of drums, severity slightly decreased immediately following repairs and then stabilized or experienced a slight increase over the subsequent few years.

While the main goal of weld overlay repairs is to stabilize bulges that suffer from high plastic strains, the observed initial decrease in severity is caused by residual stresses that result from the welding process. This favorable effect of weld metal solidification that results from welding on one side of a bulge in a cylindrical shell was confirmed using finite element simulation of the welding process. The subsequent mild increase of plastic strain over time is likely due to the partial gradual relaxation of these residual stresses under high thermal and mechanical loads generated by operation.

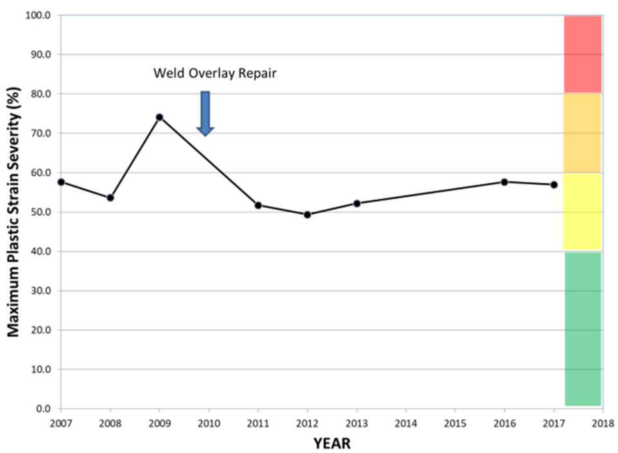

Fig. 6 Severity History of a Representative Bulge after Weld Overlay Repair

For the set of drums as a whole, the following observations can be made:

1. While the above long-term repair process was successful in stabilizing severe bulges, bulging severity continued to increase in unrepaired bulges. Repairs had no observed impact on bulging severity of unrepaired areas.
2. Weld overlay reinforcements of circumferential seams have helped in reducing cracking tendency at these welds.
3. With few exceptions, repaired areas have not cracked again despite remaining deformation and high plastic strain. The few uncharacteristic cracks that developed in repaired area were attributed to poor execution of weld perimeter or surface finish.
4. The process of using the laser scanning, bulging assessment, and bulge repair methods described above has helped in extending the life of this set of drums by a minimum of five years.

The advantages and disadvantages of the long-term bulge repair process utilized for these drums are summarized in Fig. 7. The advantages of the process were evident from above performance data. Disadvantages include (1) stress risers from poor welding that can result in cracks as described above, (2) the difficulty of inspecting weld overlays from the outside surface of the drum, and (3) the apparent increase of Inconel hardness over time.

CONCLUSIONS

In this paper, the performance of a set of eight coke drums that received long-term bulge repairs is examined. The repair process consisted of using the laser scanning, bulging assessment, and automated weld overlay methods described in this paper. Data discussed in this paper shows the following:

- The above process of long-term bulge repairs was successful in stabilizing bulges with high plastic strains in subject drums.
- Typically, plastic strain severity initially decreases after applying weld overlays on bulges but later mildly increases after years of service.
- Locations that were weld overlay repaired have not cracked again in the body of the repairs.
- The long-term bulge repair process described in this paper has helped in extending the life of this set of drums by a minimum of five years.

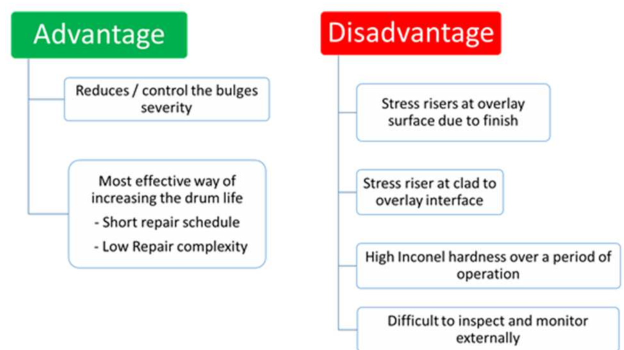

Fig. 7 Advantages and disadvantages of long-term bulge repair process

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