A DB RILEY TECHNICAL PUBLICATION

RECENT EXPERIENCE IN DISSIMILAR METAL WELD FAILURES

by

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Presented at the
International Conference on Boiler Tube Failures in Fossil Plants
Sponsored by EPRI and TVA
November 11-13, 1997
Nashville, Tennessee

RST-148

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ABSTRACT

Recent experience with dissimilar metal weld (DMW) failures and evaluations includes tube-to-tube and lug-to-tube weldments. These components are found in the reheater and superheater section of boilers designed by different OEMs. The service performance of DMWs is primarily a function of the weld metal composition, which is either an iron-based austenitic stainless steel or a nickel-based filler metal. Each of the two compositions can be characterized by a distinct DMW failure mechanism. However, the performance is also influenced by design features and operating characteristics of the boiler, including operating temperatures and pressures, load swings, unit cycling and individual component design parameters. Using the industry-generated database, remaining life estimates of cracked DMWs are possible. These estimates have been very conservative in some cases. Therefore customization of the estimate can be developed by assessment of the unique performance features of each boiler on a case-by-case basis. These exercises in life expectancy can be facilitated by use of computer software developed for this purpose.

INTRODUCTION

Boiler tube failures have been cited as the primary cause of fossil-fired plant forced outages with failures of steam-touched tubes accounting for a large part of those forced outages(1). Improving unit availability through accurate remaining life estimates becomes important to metallurgists and plant engineers alike. Dissimilar metal weld failures are an important subcategory of the above population in that they constitute a known failure point. Metallographic examination of failures and samples extracted for life estimates has been used in conjunction with industry survey data in an attempt to determine those factors which sometimes cause the welds to survive extended service in the boiler and fall outside the life expectancy distribution. Some reasons for the apparent increase in life were examined by use of the PODIS code(2).

INDUSTRY SURVEY DATABASE ON LIFE EXPECTANCY OF DMWS

A survey of plant experience with DMW failures was compiled by Mr. Paul Haas of American Electric Power Service Corporation (AEPSC) in the late 1970s as part of an ASTM-ASME-MPC task force investigation of the phenomenon of DMW failure, causes, conditions and possible "fixes" (3). The survey covered a range of welding processes (e.g. fusion, pressure, flash butt) as well as the service conditions on the DMWs (e.g. heated, non-heated). The welds in the survey generally involved a ferritic, heat-resisting grade of Cr-Mo alloy steel tubing welded by some means to an austenitic Type 300 stainless steel. Considering only the fusion welded DMWs between A213 T22 tubing and A213 Type 300 stainless steels welded with austenitic (iron-base) filler metal and the same combination of base metals welded with a nickel-base filler material (e.g. ENiCrFe-3) the task force survey yielded the following life expectancy distributions:

- for heated DMWs with iron-base fillers, the time to initial failure ranged from 29,000 to 125,000 hours with a mean time to initial failure of 74,000 hours
- heated DMWs with nickel-base fillers had a range of 40,000 to 120,000 hours with a mean time to initial failure of 100,000 hours

The survey noted inconsistencies regarding the service life of both types of DMWs. Both types of welds had service records at some participating plants well in excess of the ranges reported in the survey. The number of start-up cycles was observed to have a significant effect on life.

The foregoing distributions, if used to predict remaining life of samples removed from the units studied for this paper, would underestimate the service hours already experienced by these samples. The work performed in the current study included metallographic and microhardness data from the samples in our test population. This was compared to data generated for the task force reports in an effort to identify common factors and those variables from unit operating history which have the greatest impact on the life of the DMW.

SAMPLE POPULATION CHARACTERISTICS

Table 1 is a compilation of the samples used in the current study. Several of the samples were removed as a result of failures in the same component while some were removed from sister units with similar materials and operating histories. Three of the samples studied, F, G, and H, were removed as a result of a failure. The population in this study consists of samples, with the exception of two, which exceed the task force survey life distributions. Table 2 shows several of the weld metal chemistries obtained from the samples. Some irregularities with respect to AWS standard compositions were noted particularly in iron content(4). While some degree of variance is possible due to dilution with the base metal, the level of iron in samples F and G cannot completely be accounted for by weld metal dilution and therefore, the filler metals may be non-standard, proprietary alloys.

METALLOGRAPHIC RESULTS

Metallographic specimens were prepared from each DMW for microhardness testing and an estimate of the amount of damage on the weld fusion line. Figures 1a and 1b are typical cross-weld microhardness surveys of the samples. The heat affected zone (HAZ) hardness averages were consistent with those noted in both the artificially aged and service exposed samples of the EPRI research project (5). Figure 2 is a plot of the tempering of the HAZ vs.

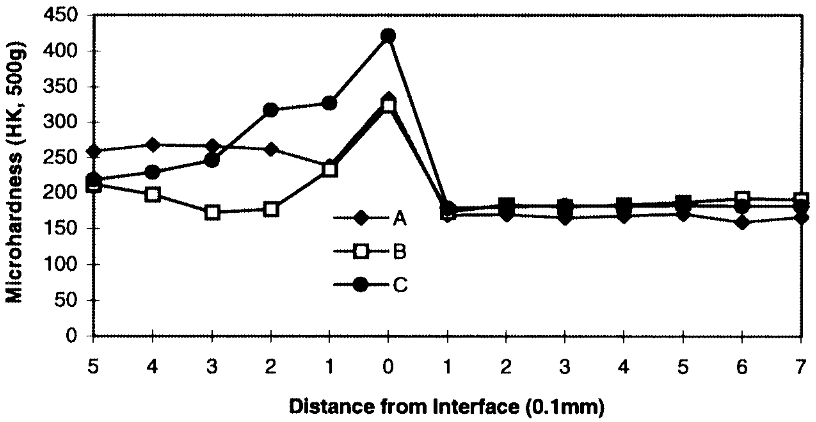
Table 1 Summary of DMW Sample Data

Sample I.D.	Component(a)	Service Time (hours)	Weld Metal Composition	Stainless Steel Tube	Alloy Steel Tube	Temperature(°F)	Pressure (psig)
A	Superheater Outlet	152,000	E309	1.5” O.D.TP321H	1.75” O.D. T22	1010	2800
B	Superheater Outlet	195,000	E309	2.0” O.D.TP347H	2.0” O.D.T22	1010	3970
C	Reheater Outlet	195,000	E309	2.25” O.D.TP304H	2.25” O.D. T22	1000	1000
D	Superheater Outlet	109,237	Inconel 82	1.5” O.D.TP321H	1.5” O.D.T22	1000	2175
E	Superheater Outlet	174,607	Ni-based	2-1/8”O.D.TP304	2-1/8” O.D. T22	1053	2575
F	Reheater Inlet Lug *Failure*	67,500	Ni-base	A351GrCH20	2-3/4” O.D.T11	NA	NA
G	Superheater Outlet *Failure*	144,000	Inconel 132	2.5” O.D.TP304H	2.5” O.D.T22	1050	2080
H	Superheater Outlet *Failure*	145,000	Inconel 182	2.5” O.D.TP304H	2.5” O.D.T22	1050	2065
I	Reheater Outlet	290,000	Inconel A	3.0” O.D.TP321H	3.0” O.D.T22	1050	966

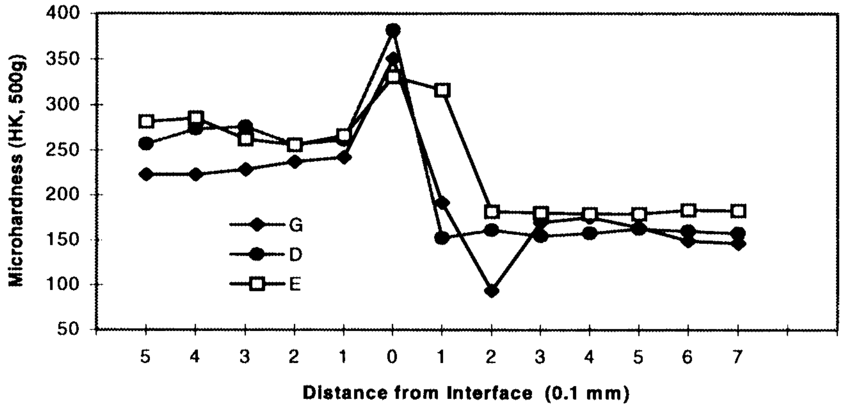
(a) All components secondary superheater or reheater, as noted

Table 2 Typical Weld Metal Composition of DMW Specimens (wt.%)

Element	B	C	F	G	H
C	0.089	0.093	0.050	0.021	0.081
Cr	22.28	20.36	16.16	16.84	16.50
Mn	1.65	1.53	6.36	2.34	6.25
Mo	0.36	0.41	0.11	0.19	0.15
Ni	13.04	11.71	Bal.	Bal.	Bal.
P	0.024	0.025	0.007	0.005	0.006
S	0.007	0.007	0.005	<0.001	<0.001
Nb	-	-	1.43	1.96	1.75
Ti	-	-	0.62	0.34	0.89
Si	0.25	0.24	0.71	0.26	0.26
Fe	Bal.	Bal.	17.33	19.02	9.26



(a) Typical Microhardness Profiles of Fe-Base Joints



(b) Typical Microhardness Profiles of Ni-Base Joints

Figure 1 Typical Microhardness Profiles of DMW Joints

(a) Variation in microhardness across the interface of the Fe-based weld metal (left) and T22 HAZ (right) of Samples A, B, and C.

(b) Variation in microhardness across the interface of selected Ni-based joints. Sample G is from a failed tube. The trough in HAZ hardness is attributed to decarburization at the fracture surface.

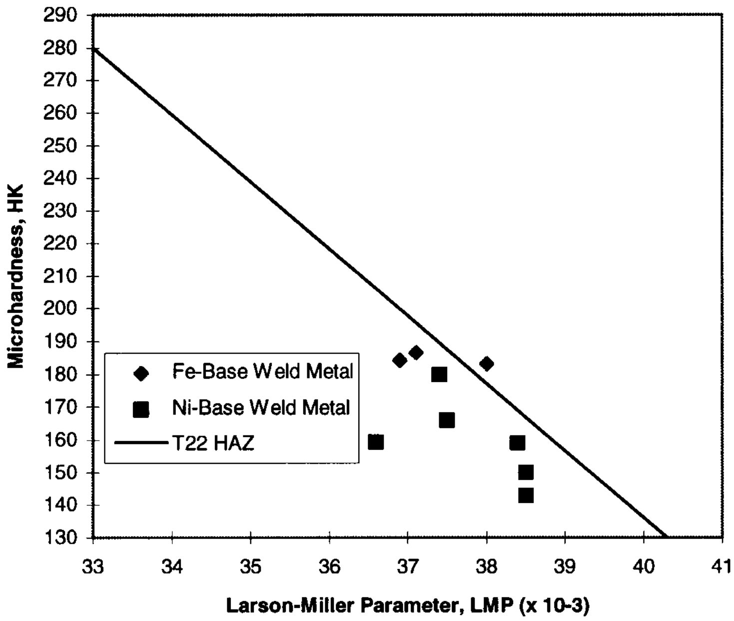


Figure 2 Microhardness of T22 HAZ vs. Larson-Miller Parameter
The T22 HAZ data generated in the current study is plotted against the best-fit line of the T22 HAZ microhardness data generated in the EPRI study (4).

Larson-Miller parameter (LMP) prepared using the best-fit line of the EPRI project and the calculated LMP from this work. These tests were performed to demonstrate that the current sample population matches the characteristics of the larger population of DMWs in the EPRI study. Note that in most cases, the data generated from this work given in Table 3 closely agrees with the EPRI samples. Two examples which did not, namely samples D and H, merited closer scrutiny. It was thought that in the case of sample D, higher tube metal temperatures caused by an overtemperature excursion were responsible for the lower HAZ hardness. The lower HAZ hardness in failed sample H was caused by decarburization of the fracture surface.

Table 3 T22 HAZ Microhardness vs. Larson-Miller Parameter, LMP

	Fe-based			Ni-based					
Sample	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
Microhardness (H_K)	183.2	186.5	184.2	159.4	179.9	166.1	150.1	142.9	159.3
P = T(20+LOG t)/1000	38.0	37.1	36.9	36.6	37.4	37.5	38.5	38.5	38.4

Figure 3 is a macrophotograph of a failure which prompted the removal of sample D, also shown. The damage mechanisms observed for the two types of welds were consistent with those historically experienced by iron-base and nickel-base joints. The iron-based joints experienced cracking along prior austenite grain boundaries (Figure 4) while the nickel-based joints showed microvoid formation and interfacial cracking which could be observed by light microscopy (Figure 5). In the cases of the non-standard weld chemistries, microcracking resembling creep failure occurred on crack paths angled away from the weld fusion line as well as interfacial cracking (Figure 6).

Figure 3 Macrophotograph of DMW Samples
The top tube exhibits features typical of a DMW failure. The failure of this tube prompted examination of the bottom tube, Sample D.

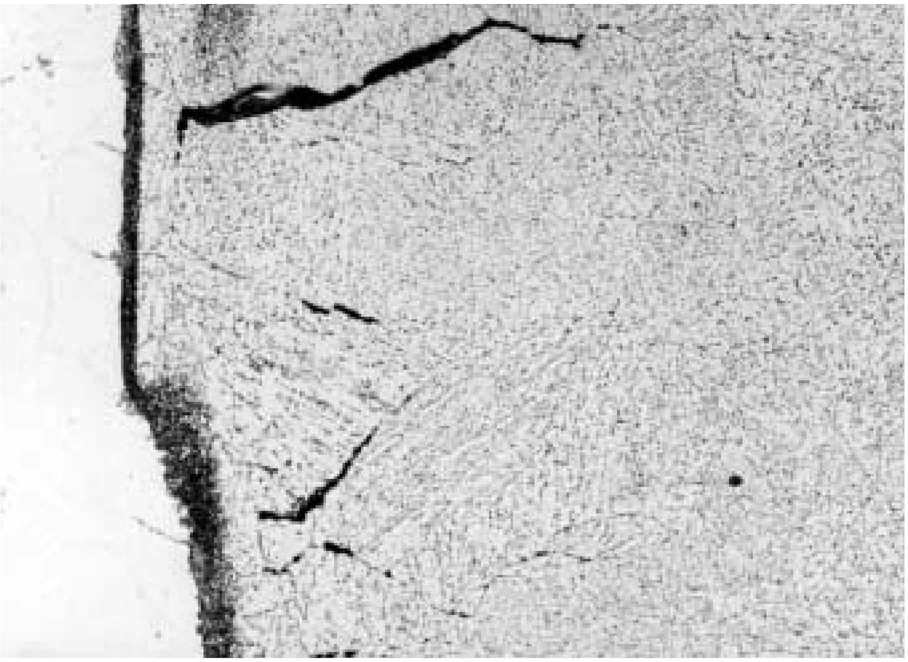


Figure 4 Typical Cracking in an Iron-based Filler Metal DMW
Creep damage and cracking is seen along prior austenite grain boundaries.
Etched in Nital. 400X

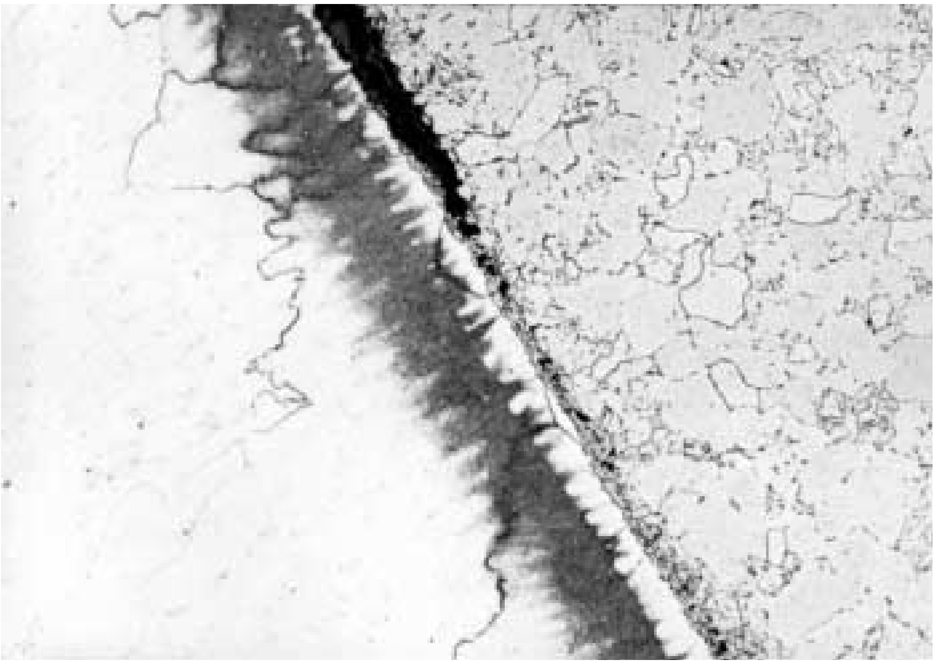


Figure 5 Typical Cracking in a Nickel-based Filler Metal DMW
Microvoid formation and cracking is seen in association with the interfacial carbides at the weld fusion line. Etched in Nital. 400X

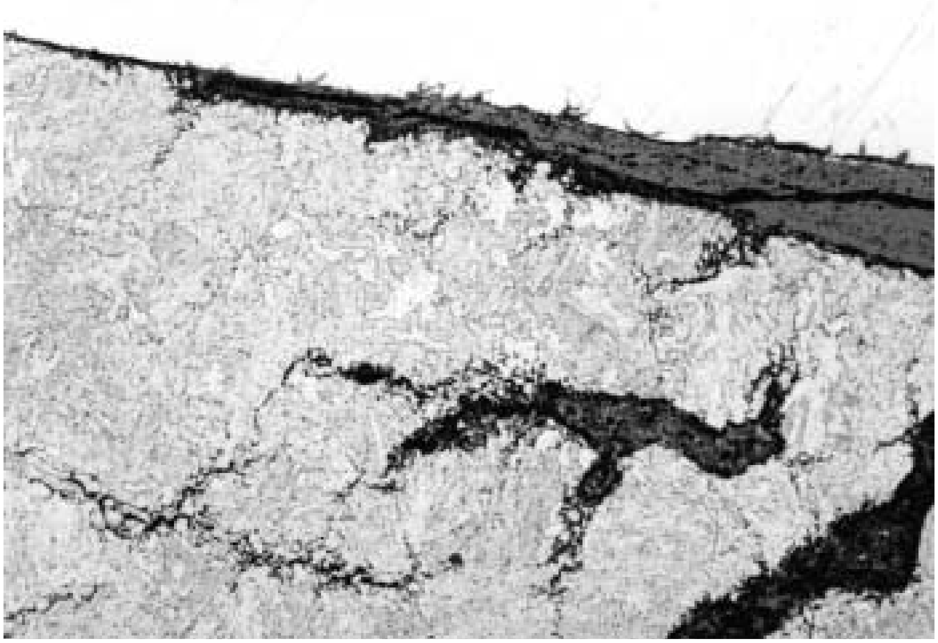


Figure 6 Cracking in a Non-standard Alloy Filler Metal DMW
Interfacial cracking and prior austenite grain boundary creep damage is seen. Etched in Nital. 400X

REMAINING LIFE ESTIMATION

The PODIS code was used to estimate remaining life of the DMWs in the current study. In this part of the study both failed and non-failed ex-service welds were first metallographically examined to produce the observed damage estimates shown in Table 4. The available data on unit operating history was then examined in order to provide data for the PODIS calculations shown in the table.

Table 4 D_{TOT} *vs.* D_{OBS} *in DMW Samples*

	Fe-based			Ni-based					
Sample	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
						failure	**failure**	**failure**	
D_{TOT}	0.46	0.169	0.309	0.15	0.19	0.65	0.96	0.92	0.65
D_{OBS}	0.448	0.145	0.554	0.250	0.222	0.85	1.00	0.508	0.330

The expression used to calculate the total damage , or D_{TOT}, is expressed as;

$$D_{TOT} = D_I + D_P + D_S$$

where D_I = intrinsic or self-damage
D_P = primary system load damage
D_S = secondary system load damage

The term intrinsic or self damage refers to the damage from self-generated loads caused by differences in thermal expansion of the materials in the DMW. This term is not used in analyses of nickel-based joints. Primary system loads are axial pressure and deadweight loads. Secondary system load damage is caused by restrained thermal expansion of the tube assembly leading to bending loads. The secondary damage term also accounts for creep damage induced during hold periods. A value of unity is considered to equal failure. Therefore a fraction of the life of the DMW expended is expressed by values of D_{TOT} less than one.

In general, the iron-based joints had the best agreement between observed and calculated damage. In the case of nickel-based joints, some improvement in the degree to which the observed damage correlated to the calculated damage was obtained by closer examination of tube metal temperatures via oxide scale estimation. An additional improvement was made in the calculation of the D_S factor by considering how the unit was operated over its life. For example several units in the study were base-loaded as new units but for a significant portion of their recent service years were used as peak load units which increases the influence of the secondary system load damage on the total life. Figure 7 is a plot of the results obtained in the damage study. The general agreement of the observed damage vs. calculated damage is a strong argument for accurate determination of critical operating variables, such as any changes in the loading and cycling of the unit. In the case of sample D, foreknowledge of an overtemperature excursion can aid in assessing system load damage.

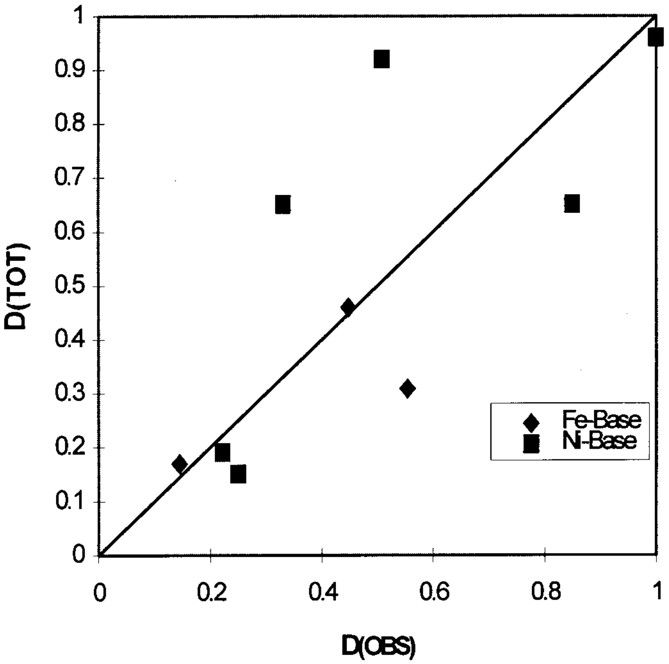


Figure 7 Calculated Total vs. Observed Damage in DMW Samples

Figure 8 is a re-plot of the data used in the original PODIS code evaluation. Better agreement between the observed damage and calculated damage (Table 5) was obtained by using the DMWLIFE computer code developed by Structural Integrity(6). The DMWLIFE program improves the estimated life of nickel based joints because the coefficients in the expressions for **D_P** and **D_S** were developed empirically by analyzing many samples from participating utilities.

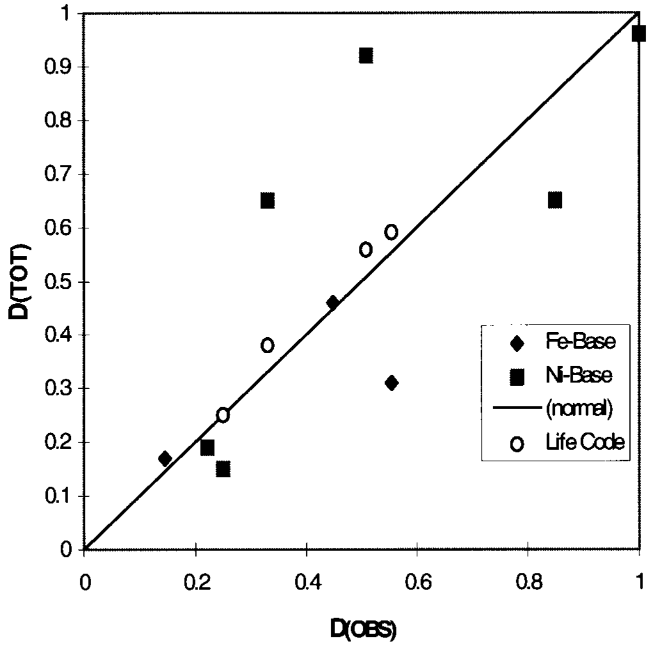


Figure 8 Calculated Total vs. Observed Damage in DMW Samples Using DMW LIFE Code

Table 5 $\mathbf{D}_{TOT}$ *vs.* $\mathbf{D}_{OBS}$ *vs.* $\mathbf{D}_{TOTLC}$ *in DMW Samples*

	Fe-based			Ni-based					
Sample	**A**	**B**	**C**	**D**	**E**	**F** **failure**	**G** **failure**	**H** **failure**	**I**
$\mathbf{D}_{TOT}$	0.46	0.169	0.309	0.15	0.19	0.65	0.96	0.92	0.65
$\mathbf{D}_{OBS}$	0.448	0.145	0.554	0.250	0.222	0.85	1.00	0.508	0.330
$\mathbf{D}_{TOTLC}$	0.46	0.169	**0.590**	**0.250**	0.19	0.65	0.96	**0.558**	**0.380**

SUMMARY

The samples in this study were evaluated in an effort to identify some factors in the operating histories of the units from which they were taken that could account for the apparent extended life of the DMWs. The iron-based samples showed the best agreement between observed and predicted damage. This confirms industry experience. The factors which appeared to be most critical for accurate remaining life prediction were the number and severity of any overtemperature exposures that the DMWs were subjected to as well as significant changes in operation of the unit, (i.e. base-loaded vs. cycled). For example, in the case of sample G, ignoring a significant change in operation of this unit (in 1979) from base-loaded to peaking operation would have underpredicted the damage to the DMW. The calculated $\mathbf{D}_{TOT}$ of 0.96 would have been 0.55 if the increase in number of cycles had not been taken into consideration. In the case of sample H, the lack of operating history yielded an overestimate of the damage to the DMW. These findings underscore the need for detailed boiler operating histories to be recorded and kept by plant personnel.

ACKNOWLEDGMENTS

The authors wish to thank AEP and DB Riley management for permission to publish these results. Mr. David Nesbitt of Tennessee Valley Authority was very helpful in supplying data for this paper.

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