

# Effects of Furnace Atmosphere on Heat Treat Cracking of René 41 Weldments

*The effects of oxygen are determined with the aid of a new circular-patch restraint specimen and a method of on-heating acoustical analysis*

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## Introduction

The influence of furnace atmosphere on the susceptibility to post-weld heat treat cracking of the precipitation hardenable nickel base superalloys has been the subject of previous studies (Refs. 1, 2). Although the results of these studies varied somewhat, an increased resistance to heat treat cracking was reported using inert atmospheres and vacuum. Due to experimental shortcomings, these prior results were qualitative in nature and, therefore, subject to some speculation. These shortcomings were overcome in recently completed Air Force sponsored research programs (Refs. 3, 4) with the development of a dissimilar alloy crack-susceptibility specimen (Ref. 5) and an acoustic emission technique (Ref. 6) for monitoring cracking events during

heat treatment. The subject specimen was found to be reliably reproducible from both a fabrication and test result standpoint and the acoustic emission technique provided a method for obtaining quantitative information from crack-susceptibility tests. Consequently, data were obtained which more precisely characterized the influence of furnace environments on post-weld heat treat cracking.

The primary objective of these studies was to determine the effects of oxygen on the susceptibility of René 41 to heat treat cracking. Possible benefits of excluding oxygen from the furnace environment have been reported by other investigators (Refs. 2, 7) including the suggestion that the absence of oxygen from the furnace atmosphere during heat treatment would eliminate postweld cracking (Ref. 7). The results reported here are from tests conducted with hydrogen, helium, and vacuum furnace environments. These data are compared with results of air atmosphere control tests and tests conducted using oxygen atmospheres. The scope of work described herein includes crack-susceptibility evalua-

tions and metallographic (replica and scanning electron microscopy) and acoustic emission analyses.

## Procedure

### Materials

The results reported were obtained with 0.060 in. René 41 sheet product from two heats of material of the chemical compositions noted in Table 1. Both heats represented production grades of the alloy with an ASTM grain size of 7-8. The work reported using the square frame specimen was conducted with Heat No. 7470 material whereas Heat No. 6842 product was used for the circular frame specimen tests.

### Specimen Details and Fabrication

Initial tests with varying furnace atmospheres were conducted with a 7 in. square frame configuration as detailed in Fig. 1. Subsequent vacuum environment tests were conducted with 7 in. circular frame specimens as depicted in Figs. 2 and 3. Both specimen types utilize AISI 304 stainless steel frames which provide augmented thermal stressing during heat treatment. In both specimens, the 4½ in. diam by 0.062 in. disk insert is the René 41 test material of interest. As seen in Fig. 1, the square design consists of two elements; the René 41 disk insert and the 1 in. thick frame. The circular specimen seen in Fig. 3

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is a three element configuration. The dimensions of the disk insert and backing groove were the same in both instances.

These specimens were fabricated by first welding the disk insert to the frame and then making the 1½ in. diam inner (test) weld as a full penetration bead-on-sheet deposit with filler metal addition. The cover and evacuation tube assembly were then welded to the circular frame specimen to complete the assemblage shown in Fig. 3. All welding was performed with semiautomatic gas tungsten-arc equipment consisting of a stationary electrode, current slope control, automatic cold wire feed system, and a variable speed circumferential positioner. Argon was used as the torch shielding gas and helium as the backing gas. Hastelloy W filler metal was used in all cases.

Both specimen types were used as "integral retorts" to provide the desired heat treating atmosphere. This was accomplished with the square specimen by plumbing copper tubing to the backing gas ports and using the backing groove chamber as a retort. As found in earlier work (Ref. 3), the crack initiation (critical) surface was the root surface side of the weldment and, therefore, atmosphere control using the backing groove chamber was considered adequate for these studies.

The square frame was, however, considered inadequate for vacuum (partial pressure) tests due to development of differential stresses arising from the evacuation of the backing groove chamber. Consequently, the circular specimen was developed wherein both surfaces were parts of evacuated chambers (via the two ¼ in. diam holes shown in Fig. 2) thus eliminating pressure differentials between the root and top surfaces of the weld.

### Heat Treating

Postweld heat treatment consisted of slow heating (at an average rate of 15 F/min) in a furnace set at some preselected temperature above temperatures at which on-heating cracking is normally encountered. Heating rate control was achieved by insulating the test specimen, as shown in Fig. 4, with fused silica foam which also served to minimize differential heating effects.

Temperature profiles were run on both square and circular specimens to assure temperature uniformity within the aging temperature range (about 900 F and higher). Thermocouples used for monitoring temperatures during on-heating, were percussion welded to each specimen; to the top center of the disks in square frame specimens and to the top center of the cover on circu-

**Table 1 — Chemical Composition of Rene'41 Material Used in Tests**

Heat no.	C	S	Mn	Si	Cr	Mo	Co	Ti	Al	B	Fe	Ni
7470	.074	.008	.03	.08	18.75	9.68	10.92	3.36	1.56	.007	.51	bal.
6842	.075	.004	.05	.10	18.80	9.74	11.27	3.11	1.57	.005	1.17	bal.

**Table 2 — On-Heating Crack-Susceptibility Data Showing the Effects of Furnace Atmosphere on the Susceptibility of Rene 41 Sheet<sup>(a)</sup> (Heat No. 7470) Weldments to Heat Treat Cracking**

Data Obtained with Square Frame Specimen (See Fig. 1)

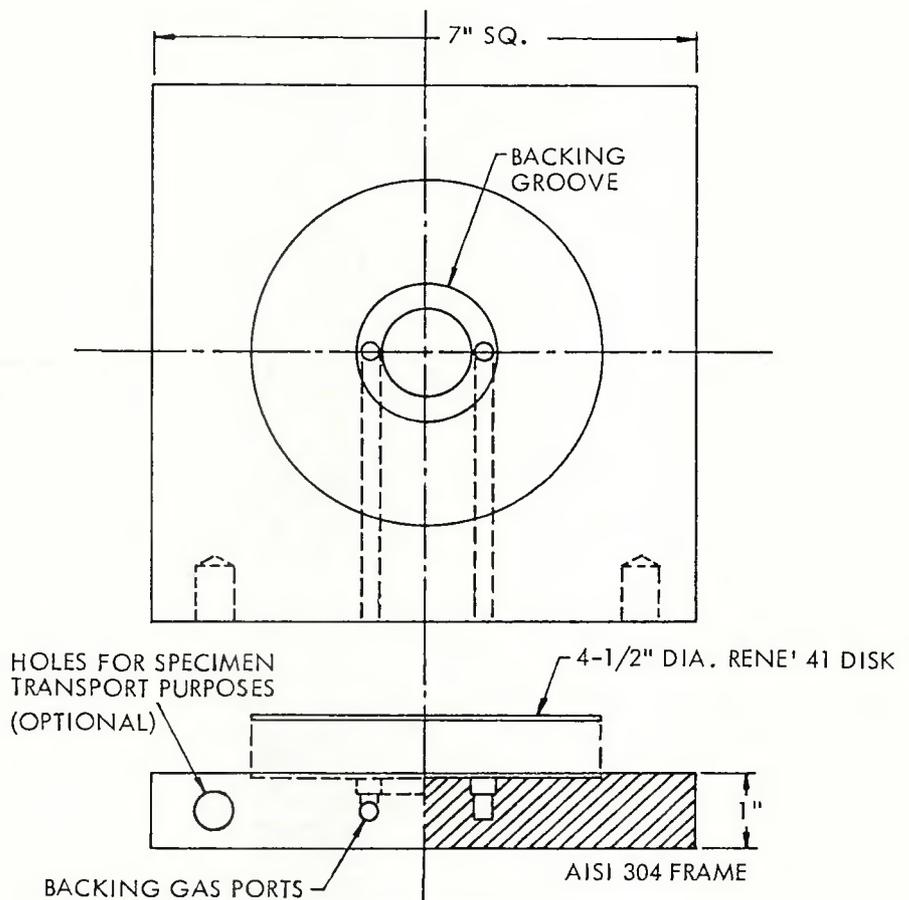
Specimen no.	Heat treat environment	Temp., onset gross cracking F <sup>(b)</sup>
Control specimens <sup>(c)</sup>	Air	1360
1(113)	Oxygen	1380
2(124)	Oxygen	1370
3(125)	Oxygen	1360
4(121)	Hydrogen	1415
5(122)	Hydrogen	1385
6(123)	Hydrogen	1405
7(126)	Helium	1380
8(127)	Helium	1375
9(128)	Helium	1405
10(118)	Partial Vacuum <sup>(d)</sup>	1350
11(119)	Partial Vacuum <sup>(d)</sup>	1345
12(120)	Partial Vacuum <sup>(d)</sup>	1350

(a) Preweld condition — mill annealed.

(b) Parameter defined in Ref. 6.

(c) Data from Ref. 3 and 4.

(d) Produced with "roughing" pump.



**Fig. 1 — Square frame crack-susceptibility specimen**

lar frame specimens. Temperatures were recorded continuously during thermal cycling until the specimen was removed from the furnace.

Temperature variations above 900 F were found to be consistently within 10 deg indicating the insulation effectiveness of the fused silica "cold top" and "base" for minimizing thermal shock of the disk insert and achieving a slow heating rate during on-heating. These results revealed that thermal conduction through the frame was the primary mechanism of heating the disk insert.

The differing gas ( $H_2$ , He,  $N_2$ , and  $O_2$ ) atmosphere tests were conducted with the square frame specimen (see Fig. 1). These tests were performed using slightly positive pressures with gas flowing through copper tubing to the backing groove chamber, out of the opposite port through copper tubing and exhausting to the atmosphere. The incoming line was coiled and the coils inserted into the furnace along with the test specimen; the coils served to preheat the in-

coming gas to avoid cooling effects due to its impingement on the inside surfaces of the disk insert.

Partial pressure (vacuum) tests were also conducted with square frame specimens using a roughing pump for evacuation purposes. Several questions were introduced with this setup including the effects of out-gassing of the furnace cement used for sealing purposes and the pressure differential developed by evacuation of one side of the specimens only. These questions led to the development of the circular frame specimen (Figs. 2 and 3) which contains features that circumvented these possible difficulties.

The vacuum system used with the circular frame specimen included a 4 in. diam diffusion pump which assured attaining partial pressures comparable to or better than those routinely obtained with production vacuum heat treating facilities. Coupling of the test specimen to the vacuum system was accomplished by attaching the vacuum line to the

evacuation tube outside of the furnace. The procedure for these tests included evacuation of the specimen outside of the furnace until a low partial pressure was attained and then allowing for a pumpdown period of at least two hours or overnight before conducting the heat treat test. Instrumentation of the specimen was accomplished during the pumpdown period. These specimens were insulated with fused silica foam in the same manner as the square specimens.

**Table 3 — On-Heating Crack-Susceptibility Control Test Results for René 41 Specimens<sup>(a)</sup> Heated in Air**

Data Obtained with Circular Frame Specimen (See Fig. 2)

Specimen no.	René 41 heat no.	Temp., onset gross cracking F
1 (100)	7470	1375 <sup>(c)</sup>
2 (101)	7470	1360
Square frame ref. data <sup>(b)</sup>	7470	1350-1370
3 (102)	6842	1335
4 (109)	6842	1350
5 (110)	6842	1340
Square frame ref. data <sup>(b)</sup>	6842	1335-1340

- (a) Preweld condition — mill annealed.
- (b) Summary of data from Ref. 3 and 4.
- (c) Test conducted without cover (See Figs. 2 & 3).

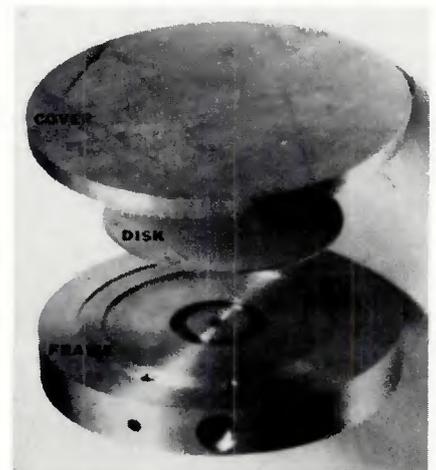
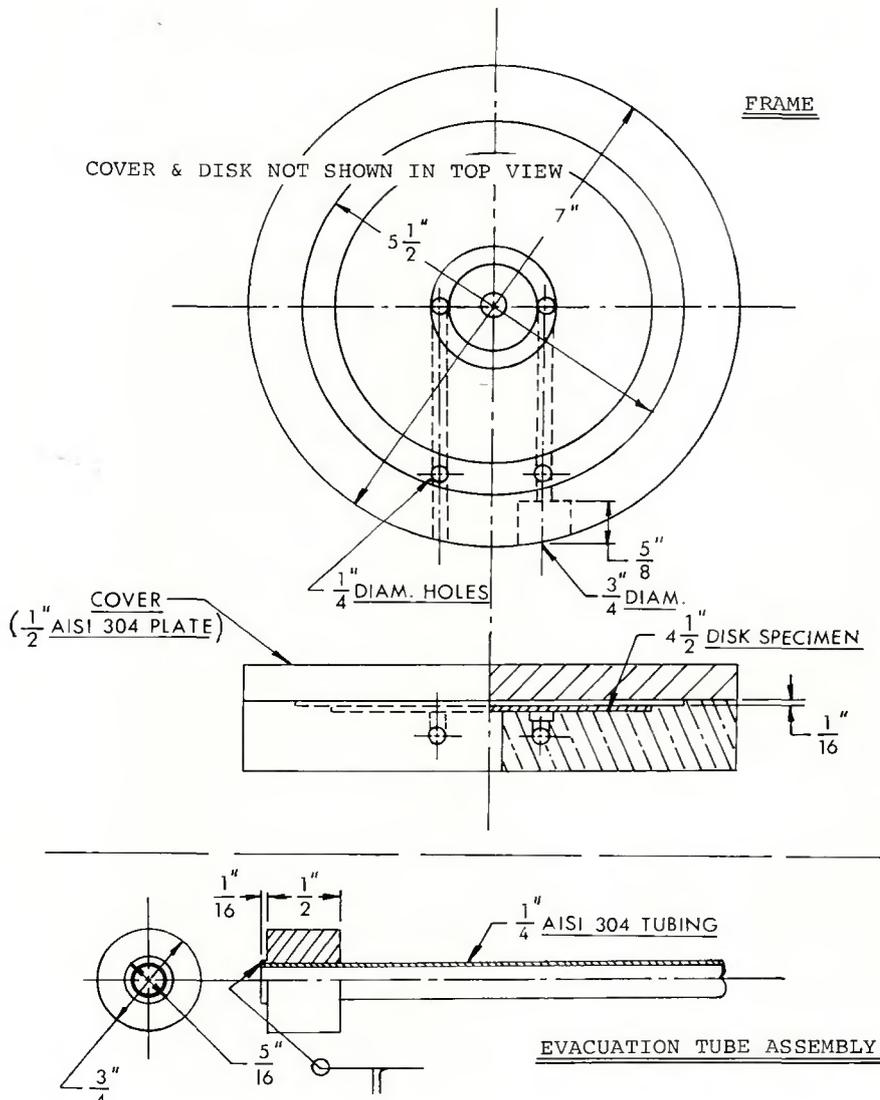


Fig. 3 — Circular frame crack susceptibility specimen unassembled (top) and completely fabricated (bottom)

Fig. 2 — Circular frame crack-susceptibility specimen

## Acoustic Emission Monitoring During Heat Treatment

Specific details on the acoustic emission technique developed for this study are contained in Ref. 6. An essential feature of this technique was the use of an "acoustic conductor" which allowed coupling of the transducer outside of the furnace environment. This approach permitted the direct use of acoustic emission for monitoring cracking events during heat treatment which was not previously considered feasible.

The data obtained included cracking events (acoustic activity) recorded as a function of on-heating temperature and time. Methods were developed which permitted precise analyses of acoustic characteristics in terms of cracking process features. Thus it was possible to distinguish various stages of fracture including subcritical events, slow crack growth, and rapid unstable crack propagation. As noted (Ref. 6), acoustic emission analyses provided a method for correlating the resistance to crack initiation and extension and qualitatively rating the heat treat crack susceptibility of differing alloys. Consequently, subtle differences in cracking behavior due to varying fur-

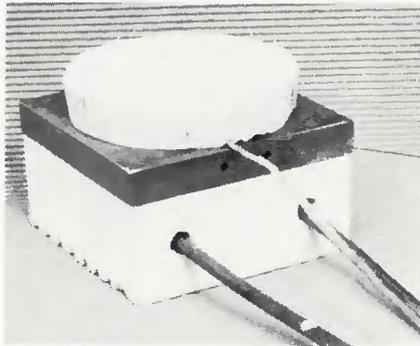


Fig. 4 — Ensemble used for controlled temperature rate in on-heating crack susceptibility tests. Tongs inserted in base are used for specimen transport purposes.

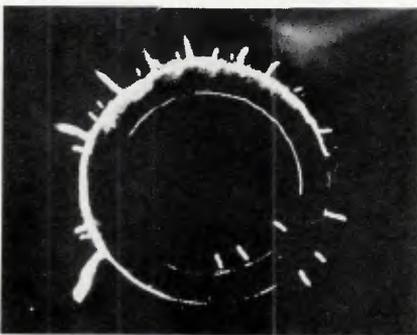


Fig. 5 — Black light photograph of on-heating gross cracking experienced during heat treating in a hydrogen furnace atmosphere

nance atmospheres were readily distinguished.

The only difference in technique for the square and circular frame specimens was the attachment location of the acoustic conductor. The conductor was percussion welded to both specimen types; to the center of the disk insert of the square specimen and to the outside edge of the cover on the circular specimen (see Figs. 1 and 3).

## Results and Discussion

### Restraint Test Evaluations

Initial crack-susceptibility tests using square frame specimens (Fig. 1) were conducted by controlling the atmosphere of the backing groove chamber. Copper tubes were inserted into the backing gas ports with one tube serving as the inlet and the other as an outlet. Each tube was snug-fitted into the port and sealed with a fillet of adhesive (Sauereisen No. 1 Paste Adhesive Cement\*) at the tube-frame junction.

Several reasons will explain why it was considered adequate to conduct these tests by controlling only the backing groove chamber atmosphere. It was established early in the program (Ref. 3) that crack initiation occurred on the root (inside) surface of the René 41 disk. This was verified by (1) the lack of deformation surrounding the cracks on the inside surface as compared with visible deformation noted on the outside surface of the specimen, (2) deformation twinning observed metallographically at the outside surface and none observed at the inside surface surrounding crack networks (3) part-through cracking on the inside surface with no evidence of cracking on the outside surface, (4) through-thickness

cracks being longer on the inside surface than on the outside, and (5) the existence of fluorescent penetrant detected microcracking on the *inside surface only* of specimens which did not experience gross cracking. Consequently, since it was possible to monitor subcritical cracking events during on-heating, this method of furnace atmosphere control and initially considered quite adequate.

Results of these initial tests are summarized in Table 2. The oxygen, hydrogen, and helium tests were conducted by first purging the backing groove chamber outside of the furnace and then metering the gas flow rate with a micrometer valve prior to inserting the specimen into the furnace. The gas flow rate was sufficiently low not to change the heating rate of the specimen. The backing gas ports in the test specimen were located towards the rear of the furnace, allowing preheating of the gas during its flow through the inlet tube to the rear of the furnace.

The partial vacuum tests were conducted using a roughing pump for evacuation. Due to the small size of the chamber, partial pressures of  $20\mu$  of Hg or less were conveniently achieved. All of the specimens were pumped down (evacuated) prior to their insertion into the furnace. An interesting aspect of these tests was the ability to detect when an initiated, part-through, crack had become a through-the-thickness crack; the roughing pump made a distinguishable surging noise as soon as the crack extended to the outside of the specimen, permitting air filling of the backing groove chamber.

Results of the tests summarized in Table 2 reveal that furnace atmospheres have an influence of René 41 on postweld heat treat cracking behavior. The gross cracking (OGC) tem-

\*A product of the Sauereisen Cements Co., Pittsburg, Pa.

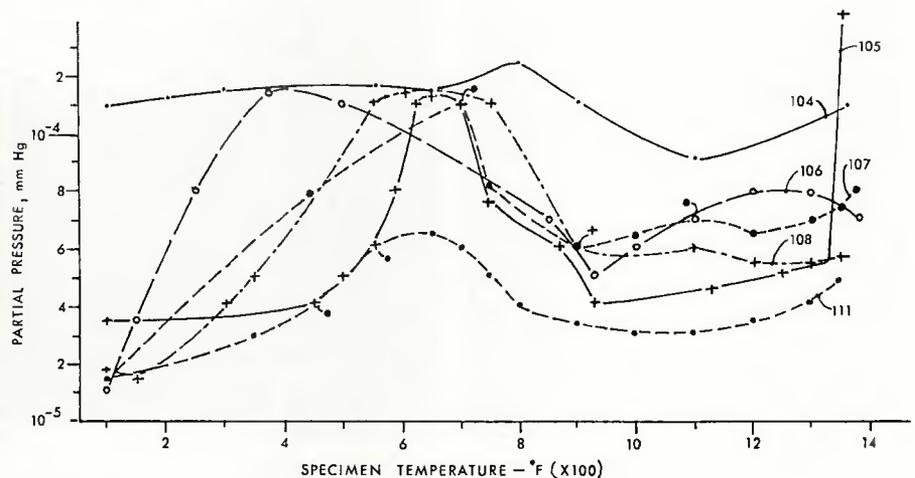


Fig. 6 — On-heating partial pressure profiles obtained for vacuum test series

peratures of the oxygen tests were comparable to those of air atmosphere tests; this is not unexpected, since the influence of oxygen is probably maximum at oxygen contents less than that of air. Both hydrogen and helium increased the OGC temperature, with hydrogen exhibiting the greatest effect.

One of the unusual effects noted was the extent of gross cracking obtained with the hydrogen specimens. The most general form of gross cracking observed with air atmosphere specimens was an approximately 180 deg circumferential crack with or without small radial cracks extending from its extremities along the grain direction of the sheet. As shown in Fig. 5, the cracking of hydrogen atmosphere test specimens was different in that a multiplicity of radial cracks, independent of grain orientation was obtained. The primary circumferential cracks, however, were quite similar to those observed with air atmosphere test specimens as influenced by grain direction and location.

The fact that the partial vacuum tests showed a lowering of the OGC temperature was attributed to the possible tension stressing of the inner (root) surface of the specimen due to the imposed pressure differential across the sheet thickness. The partial vacuum tests were also assumed to be subject to the influence of any residual oxygen originating from air outgassed from the adhesive fillets at the tube joints. The possible effects of the pressure differential created by simply evacuating the backing groove chamber and the possibility of air outgassing of the adhesive fillets led to the development of the circular frame specimen shown in Fig. 2 and 3.

Crack-susceptibility test results obtained with the circular frame specimen (Fig. 2) are summarized in Tables 3 and 4. Data obtained for control purposes with air atmospheres are shown in Table 3 and vacuum environment test results are contained in Table 4. The air atmosphere tests were conducted with specimens representing two heats of René 41 (heats 7470 and 6842) and the vacuum data were obtained with specimens produced with heat No. 6842 material. The data of Table 3 provide a correlation of air atmosphere test results obtained with circular and square frame specimens configurations. As these data indicate, there is essentially no difference in the gross cracking temperatures of circular and square frame specimens for both heats and material. This suggests that air atmosphere data obtained with the standard square frame were valid for correlation purposes with the vacuum test data obtained with the circular frame integral-retort specimen.

A comparison of the gross cracking temperatures obtained with the vacuum environment tests summar-

ized in Table 4 with the air atmosphere results in Table 3 clearly show that the use of a "good" vacuum for heat treating purposes will not significantly increase the resistance to postweld heat treat cracking. The noted 10 to 15 deg increase in the gross cracking temperature is of the same order of magnitude as the increase observed by simply lowering the weld energy input (ref. 3).

It is important to note the possibility of a temperature difference between the specimen disk and the top surface of the cover. With the vacuum tests, heating of the disk insert is accomplished by conduction through the base metal, whereas the air atmosphere specimens are additionally heated by the air in contact with the disk surfaces. Consequently, the disk insert temperature would probably lag the temperature of the cover element surface. If this thermal differential actually existed, it is possible to conclude that a vacuum environment has no effect on gross cracking because the actual gross cracking temperature would be slightly lower than those noted in Table 4.

With regard to the quality of the vacuum used for these tests, attention should be drawn to the initial maximum partial pressure data summarized in Table 4. Excluding the first two specimens for reasons noted in the table, initial pressures were quite low ranging from 1 to  $1.8 \times 10^{-5}$  mm Hg with maximum pressures to 5 to  $8 \times 10^{-5}$  mm Hg occurring in the 900F to gross cracking temperature range. It is significant that the gross cracking temperatures of the first two specimens shown in Table 4 agree quite favorably with the gross cracking temperatures of the latter four specimens. These data are in agree-

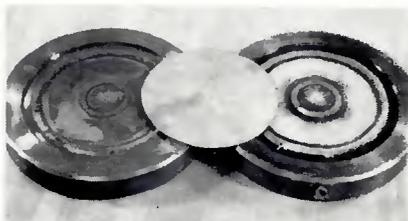


Fig. 7 — Comparison of surface oxidation due to air atmosphere (left) and vacuum environment (right). Disk in center is as-received material

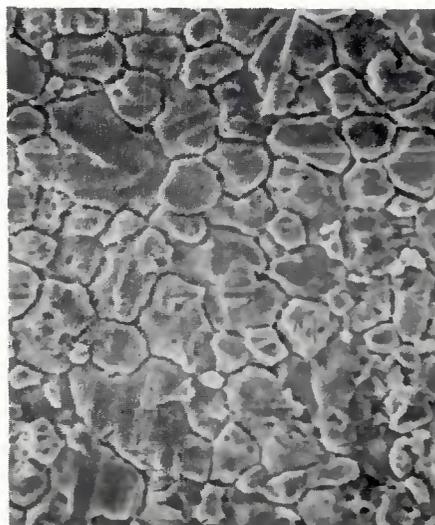


Fig. 8 — Scanning electron micrographs showing selected intergranular oxidation of the HAZ surface due to heat treating in an air atmosphere (left) and a vacuum environment (right). Center example was taken from a vacuum specimen which developed a leak during on-heating (X1000, reduced 18%)

ment despite the fact that the first specimen was not adequately cleaned prior to heat treating and the second was fabricated using a frame in which the top surface access holes were omitted.

Partial pressures measured during on-heating for each of the tests summarized in Table 4 are plotted as a function of specimen temperature in Fig 6. Of note in these plots is a characteristic increase in pressure which peaks out in the 500 to 700F temperature range. This effect is the result of surface outgassing during heating and is clearly a function of the degree of cleanliness associated with the preparation of the specimens.

For example, an effective initial low pressure could not be obtained with specimen 1(104) due to residual machining oil in the backing gas ports, although the pressure did drop during on-heating above 900F. Specimen 2(105), in which the top surface access ports were omitted, increased in pressure rapidly during on-heating and then declined during heating above 800F; the surge in pressure at the gross cracking temperature is due to the sudden evacuation of the upper chamber resulting from the development of through-thickness cracks.

The low partial pressure cycle exhibited by specimen 5(111) is the result of meticulous cleaning procedures used to verify the influence of outgassing on partial pressure variations during on-heating. The primary difference in the preparation of this specimen as contrasted with the others was the belt grinding of the inside surface of the cover element to remove the mill surface material which was thought to be a predominant source of outgas.

#### Metallographic Analyses

The effectiveness of the vacuum environment is illustrated by the specimens shown in Fig 7. The specimen on the left is an air atmosphere test specimen and the one on the right is a vacuum test specimen. The disk placed on the two specimens illustrates the luster of the as-received material for comparison purposes. Although not evident in this photograph, the surfaces of the disks from the vacuum tests appeared "cleaner" after heat treatment than they were prior to heat treat cycling.

The effects of oxygen were clearly revealed during the routine metallographic examination of test specimen fractures. These effects are shown in the scanning electron micrographs on Fig. 8, where selective intergranular oxidation of heat-affected zone surfaces is evidenced for varying oxidation conditions. The micrograph on the left shows intergranular oxidation of the heat-affected zone due to heat

**Table 4 — On-Heating Crack-Susceptibility Test Results for Rene<sup>41</sup>, Ht. No. 6842, Specimens<sup>(a)</sup> Heat Treated in Vacuum**

Data Obtained with Circular Frame Specimen (See Figs. 2 & 3).

Specimen no.	Temp., onset gross cracking F	Vacuum pressures initial	(mm Hg), <sup>(c)</sup> maximum
1(104)	1360 <sup>(b)</sup>	$1 \times 10^{-4}$	$1 \times 10^{-4}$
2(105)	1350	$3.5 \times 10^{-5}$	$4 \times 10^{-4}$ <sup>(d)</sup>
3(106)	1355	$1 \times 10^{-5}$	$8 \times 10^{-5}$
4(107)	1360	$1.5 \times 10^{-5}$	$8 \times 10^{-5}$
5(108)	1340	$1.8 \times 10^{-5}$	$6 \times 10^{-5}$
6(111)	1365	$1.5 \times 10^{-5}$	$5 \times 10^{-5}$

(a) Preweld condition — mill annealed

(b) Specimen surface slightly discolored, however, crack face appeared clean. This specimen was not ultrasonically degreased and residual machining oil probably remained in the backing groove ports which were rough surfaced and beveled.

(c) The maximum pressure noted here is that observed in the temperature range above 900 F, during which subcritical and cracking events occur. Pressure increases below 900 F were attributed to surface outgassing effects.

(d) Holes to upper chamber omitted (See Fig. 2) Pressure surge to  $4 \times 10^{-4}$  mm Hg occurred during gross cracking when through-thickness cracking resulted causing evacuation of upper chamber.

treating in an air atmosphere. The center micrograph reveals less pronounced selective attack in the immediate vicinity of a gross crack obtained with a test in which an air leak developed during on-heating. The micrograph on the right, taken in the immediate vicinity of a gross crack in a vacuum test specimen, does not show any signs of intergranular oxidation; surface indications are probably due to the opening of prior oxidation damage sites resulting from microstraining of the surface metal in the vicinity of the heat treat crack network. The abrasion marks evident in all of the examples of Fig. 8 are due to pre-weld sanding of the surfaces preparatory to welding.

A systematic scanning electron microscopy analysis comparing the fracture features of air atmosphere specimens with the features of vacuum specimens was conducted. The variations in fracture appearance between these groups of specimens were readily apparent. Examples of scanning electron micrographs comparing fracture features of air atmosphere and vacuum environment specimens are shown in Fig. 9. The micrograph to the left shows air atmosphere specimen features and the one on the right features of vacuum specimen fractures. The general oxidation of the air atmosphere test fractures is quite similar in appearance to fractures which have undergone general corrosion attack. In contrast, the vacuum specimen fractures are sharp featured and secondary cracking is more readily apparent.

A detailed replica microscopy study was also conducted to further establish microstructural feature differences associated with fractures in air and vacuum. Representative micrographs of fracture features associated with these furnace environments are shown in Fig. 10 (air) and 11 (vacuum). In both instances, fracture is intergranular and compound particles are evident on the grain facets.

The primary difference shown in these figures is the oxidation of micro-features such as compound particles and precipitate particle sites on the air atmosphere fractures. It is not apparent whether oxidation occurs as part of the fracturing process or just simply subsequent to fracture as the fresh surfaces are exposed to air. The restraint test results would suggest the latter since the difference in susceptibility to heat treat cracking of air and vacuum specimens was not significant.

Another fracture characteristic noted in this study was the common occurrence of "striations" in vacuum test specimen fractures. These striated features were also evident with air atmosphere fractures, but to a considerably lesser degree. Examples of the striated features associated with heat treat cracking in vacuum are shown in Fig. 12.

The most likely explanation for the occurrence of these stria is that they are slip plane traces accommodating the fracture process. The possibility of these striations representing cyclic crack extension similar to fatigue crack growth was considered; however, the lack of any apparent continuity of the crack front among adjacent grains did not support this idea. The presence of these striations might be consistent with fractures exhibiting greater plasticity characteristics which is somewhat supported by the slower rate of crack extension revealed by acoustic emission analyses. It may also be assumed that step-like fracturing along grain boundaries indicates a higher resistance to crack extension that does a planar separation of grains. Consequently, it might be concluded that a vacuum environment is more desirable than an air atmosphere for heat treating purposes; this is suggested by the restraint test results showing a slight increase in the gross cracking temperature using a vacuum environment.

## Acoustic Emission Analyses

Significant differences were noted in the acoustic emission cracking characteristics as influenced by an air atmosphere and a vacuum environment. These differences were noted for both *subcritical* and *gross cracking* events during on-heating. For the reader's benefit, the terminology and acoustic characteristics of heat treat cracking used here are discussed in detail in Ref. 6.

The continuous emissions and occasional low and intermediate intensity bursts normally observed with air atmosphere tests were far less pronounced with the vacuum test series. This suggests the possibility that the difference in acoustic activity is associated with selective intergranular surface oxidation as shown in Fig. 8. Subcritical microcracking indications just prior to gross cracking were more evident with the vacuum test series than with air atmosphere tests. This latter effect is undoubtedly related to the lack of surface oxidation during vacuum heat treatment. It is reasonable to assume that stress-aided intergranular oxidation in an air atmosphere would contribute to stress relaxation of surface layer material by propagation of a multiplicity of incipient surface cracks, especially at sites of prior oxidation penetration damage. Conversely, the residual surface layer stresses of vacuum test specimens would be expected to remain significant to higher on-heating temperatures thereby causing microcracking to occur later in time as precipitation hardening progressively limits the plastic strain capacity of the bulk microstructure.

The acoustic emission characteristics of "gross cracking" of air atmosphere and vacuum environment tests also varied significantly. Acoustic activity of vacuum specimens consisted of profusions of intermediate intensity continuous emissions with occasional acoustic bursts, whereas "gross cracking" of air atmosphere tests consisted of numerous acoustic bursts and much lesser amounts of continuous emissions. These variations in acoustic signatures suggest that a vacuum environment increases the resistance to "gross cracking" by shifting the mode of crack extension from predominantly unstable crack growth in air to predominantly stable (slower) crack extension. This was somewhat verified by observations of specimen fracture in that some part-through cracking was found in the vacuum test specimens; part-through gross cracking had not been observed in any of the air atmosphere test specimens except those from the interrupted on-heating series (Ref. 3).

Acoustic emission results obtained

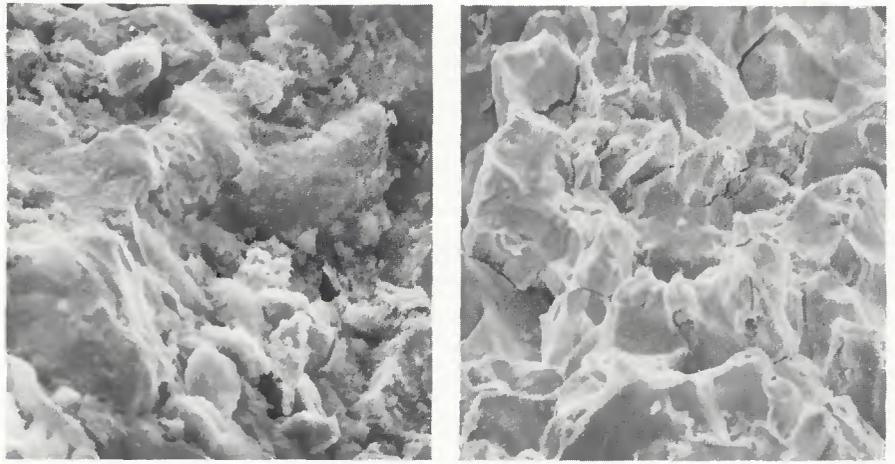


Fig. 9 — Scanning electron micrographs showing differences in fracture face features due to heat treating in an air atmosphere (left) and a vacuum environment (right). (X1000, reduced 36%)

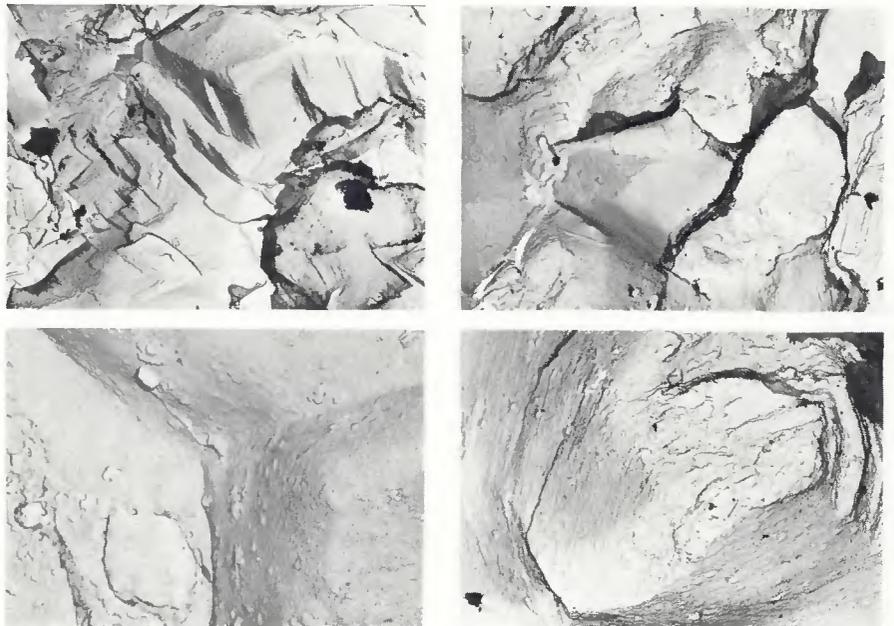


Fig. 10 — Replica electron fractographs of René 41 postweld heat treat (air) cracking. Top (X2000; bottom — X10,000, both reduced 41%)

with the earlier square frame specimen also substantiated the results of the circular frame specimen tests. The acoustic activity associated with gross cracking in hydrogen, helium, and partial vacuum atmospheres consisted of predominately low intensity continuous emissions. Acoustic emission analyses of the earlier square frame specimen series suggest that the results of these tests were probably more valid than had been originally assumed.

The temperature intervals of "gross cracking" (Ref. 6) (or time span of "gross cracking") of vacuum specimen tests were found to be less than those of air atmosphere test specimens. The occurrence of predominately slow (stable) crack extension during "gross cracking" and a shorter

temperature interval for "gross cracking" are indications of increased resistance to unstable crack propagation.

The acoustic emission data clearly show that the use of a vacuum environment as a furnace atmosphere will affect the susceptibility of René 41 to heat treat cracking. The specific extent to which the use of a vacuum environment would serve to avoid heat treat cracking is not apparent from these studies, but could be determined with tests of systematically varying restraint stress conditions. These data do show that the use of a vacuum is, at least, as effective as lowering the weld energy input, but considerably less effective than the use of selective preweld heat treatments for avoiding heat



Fig. 11 — Replica electron fractographs of René 41 postweld heat treat (vacuum) cracking. Top (X2000, bottom — X10,000, both reduced 41%)

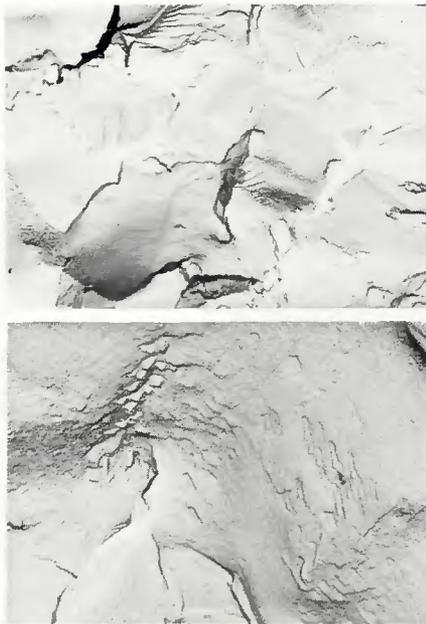


Fig. 12 — Replica electron fractographs showing striated features in René 41 heat treat (vacuum) cracking

treat cracking (Refs. 3,4).

## Conclusion

The exclusion of oxygen from the heat treating environment does not eliminate postweld cracking of René 41. Vacuum heat treating, as contrasted with heating of air, has a beneficial effect comparable to that obtained by simply lowering the weld energy input. Use of a vacuum environment slightly increases the on-heating temperature at which gross cracking occurs; this increase was similar to that achieved with weldments produced by lower weld energy input techniques.

The primary benefit obtained by the exclusion of oxygen is an increase in the resistance to gross crack extension. Acoustic emission analyses revealed that the mode of cracking shifts from predominately rapid (unstable) crack growth in air to less rapid (stable) crack extension in vacuum. Consequently, the use of vacuum for heat treating might prove useful for components in which the restraint stresses are near "threshold" value; that is, where restraint conditions are just sufficient to create

some or intermittent cracking difficulties when heat treating in air.

An increased resistance to crack propagation with vacuum heat treatment was also revealed by replica and scanning electron microscopy; microplasticity features were more prevalent in the fractures of specimens heat treated in vacuum than they were on air atmosphere test fractures.

As an approach to avoiding heat treat cracking, the exclusion of oxygen from the furnace atmosphere would be useful in any general fracture control plan. Except under marginal restraint conditions, the use of an oxygen-free furnace atmosphere is not, in itself, sufficient for eliminating postweld heat treat cracking.

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**"Long-Range Plan for Pressure-Vessel  
Research — Third Edition"**

By the Pressure Vessel Research Committee

A suitable group to carry out the research planning for PVRC was created when the PVRC Program Evaluation Committee (now designated the Evaluation and Planning Committee) was formed in 1961. This group was originally charged with the responsibility of evaluating the research work done by PVRC and others, and to prepare a "PVRC Interpretive Report of Pressure Vessel Research" to make the results directly useable to the designer and Code-making bodies. During the review and evaluation of available information, voids in the state of knowledge and the need for further research became apparent. Although these items were mentioned in the report, they needed to be organized into a consistent plan. Thus, the 18 research topics submitted to PVRC by ASME in 1959 were combined with the research problems uncovered by the PVRC Interpretive Report and published as the "PVRC Long-Range Plan for Pressure-Vessel Research" in *WRC Bulletin 116*, September 1966.

The PVRC "long-range plan" was distributed as widely as possible for review and comment. Since then, a number of additional problem areas have been suggested by the ASME BPVC as well as by other organizations and by individuals within PVRC. Therefore, to keep the long-range plan timely and up to date, the Evaluation and Planning Committee agreed that it should be re-issued every three years. In accordance with this decision, the Second Edition of the long-range plan was issued in September 1969, in *WRC Bulletin 144*, and the Third Edition in September 1972, in *WRC Bulletin 176*. Some of the problems in the Second Edition were dropped and a number of new problems were added in the Third Edition.

The list of "PVRC Research Problems" is comprised of 42 research topics, divided into three groups relating to the three divisions of PVRC, i.e., Materials, Design and Fabrication. Each project is outlined briefly in a project description giving the: (a) Title; (b) Statement of Problem and Objectives; (c) Current Status; and (d) Action Proposed.

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