~~CONFIDENTIAL~~
~~RESTRICTED DATA~~
Atomic Energy Act - 1954

MASTER

Records

WANL-TME-738

INVESTIGATION OF TITANIUM BOLT FAILURES

(Title Unclassified)

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Astronuclear Laboratory
Westinghouse Electric Corporation

~~CONFIDENTIAL~~
~~RESTRICTED DATA~~
Atomic Energy Act - 1954

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

~~CONFIDENTIAL~~
~~RESTRICTED DATA~~

MASTER

Astronuclear
WANL-TME-738

(11)

WANL-TME-738

NOTICE

This report contains information of a preliminary nature and was prepared primarily for internal use at the originating installation. It is subject to revision or correction and therefore does not represent a final report. It is passed to the recipient in confidence and should not be abstracted or further disclosed without the approval of the originating installation or USERDA Technical Information Center, Oak Ridge, TN 37830.

INVESTIGATION OF TITANIUM BOLT FAILURES

(Title Unclassified)

SPECIAL REVIEW
FINAL
DETERMINATION
Class: U

Reviewers	Class.	Date
<u>IRP</u>	<u>U</u>	<u>5-6-82</u>

INFORMATION CATEGORY

~~Confidential - RD~~

~~E. L. Layland 4/2/64~~
Authorized Classifier Date

Classification cancelled (changed to)

by authority of

H. J. C. TIC, date SEP 11 1973

PREPARED BY:

A. Filippi

A. Filippi

APPROVED BY:

E. L. Layland

E. L. Layland

F. R. Lorenz, Jr.

F. R. Lorenz, Jr., Manager
Materials Development

GROUP 1

Excluded From Automatic Downgrading
and Declassification

~~CONFIDENTIAL~~
~~RESTRICTED DATA~~

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

TABLE OF CONTENTS

	<u>Page</u>
I ABSTRACT	1
II INTRODUCTION	2
III RESULTS AND DISCUSSION	2
IV CONCLUSIONS	5

LIST OF FIGURES

<u>Figure</u>		<u>Page</u>
1	Microstructure of Bolt Material	6
2	Microstructures of Thread Contour of Failed Bolt and Roll Threaded Bolt	7
3	Large Transgranular Bolt Cracks	8
4	Photomicrographs of Titanium - Electrodeposit Interface Area	9

ABSTRACT

Five plated titanium bolts which ruptured during reactor vibration test ND 20101 were examined metallographically to gain some insight into the cause and type of failure. Samples from sixteen ruptured bolts were also analyzed for hydrogen content. Microstructural examination revealed a lack of material deformation around the thread contour implying the use of thread machining or grinding rather than thread rolling. It was subsequently discovered that threading was performed by grinding. The structure of the bolt material was characteristic of small diameter 5Al-2.5Sn-titanium bar stock being primarily fine grain (ASTM 7-8) with slight evidence of transformed beta structure, and relatively clean. No evidence of the embrittling, needle-like hydride precipitates was noted in the microstructure. This latter observation was supported by chemical analysis which placed the hydrogen content of sixteen failed bolts in the range 55 to 97 ppm. This range is well below the specification maximum of 150 ppm and the solubility limit of approximately 300 ppm. All metallographic and analytical evidence show the bolt material to be characteristic of sound 5Al-2.5Sn-titanium.

Very high magnification metallography revealed small cracks 0.0001 to 0.0005" long extending from the plating-titanium interface into the titanium. This cracking was extensive on two of the five examined bolts. These cracks were present both at the sides and root of the threads, and extended roughly perpendicular to the thread contour. There is some evidence that the cracks occur through normally present precipitate clusters, but this conclusion could not be absolutely established. It is probable that thermal shock due to thread grinding could have caused these minute fissures and subsequent propagation of some of them resulted in bolt failure. Cracking, however, may have resulted from vibration testing and not thread grinding, although this seems unlikely since they appear at both the sides and thread roots, and do not extend through the plated layers. Unused bolts from the same lot were not available for examination to absolutely establish whether these fissures were present before or after testing. An obviously brittle titanium-electroless nickel reaction zone was also found on these bolts. This zone is loaded with precipitates probably of the $Ni_x Ti_y$ type.

The environmental condition of vibration implies that the failures occurred by fatigue. This conclusion is somewhat supported by metallographic observations which did not reveal any

deformation in the material immediately adjacent to large partially-propagated cracks, and the transgranular nature of these cracks. The fatigue resistance of the bolts must have been lowered due to the presence of ground rather than rolled threads, and may have been lowered additionally by the presence of surface flaws as well as a titanium electroless-nickel brittle reaction zone.

INTRODUCTION

The ND 20101 Build I assembly was subjected to a series of lateral and torsional vibration tests on September 14, 1963. After testing, inspection revealed that twenty-eight of forty-eight titanium alloy bolts (part No. 945C630H02) had ruptured. All failures occurred through the threaded areas at the transition point between the engaged and unengaged sections. The bolts were used to fasten the aluminum alloy core support plate to a simulated core support ring. Titanium 5Al-2.5Sn bolts plated in sequence with electroless nickel and silver were used in this application. Sixteen of the ruptured bolts were obtained for metallurgical study. Five of them were metallographically mounted and polished to produce a cross-section through the threads for examination. In addition to this samples from all sixteen bolts were analyzed for hydrogen content.

RESULTS AND DISCUSSION

A survey of the titanium microstructure revealed, in general, a very fine grain, equiaxed, fully recrystallized alpha structure (ASTM 7-8). One of the examined bolts showed a somewhat duplex - part equiaxed, part transformed beta structure. The differences in structure can be attributed to variations in hot working temperatures or degree of work, and are very typical of small diameter all-alpha titanium bar products. (Small diameter bar is fabricated in the vicinity of the alpha-to-alpha-plus-beta transformation temperature and requires at least 50% work to

result in a fully equiaxed structure upon annealing.) Normal diffused light and dark field-illuminated microstructures are shown in Figure 1.

No evidence of the embrittling needle-like titanium hydride precipitate was found in the structure of these bolts indicating that plating did not result in excessive hydrogen contents. Analytical samples from all sixteen bolts verified this metallographic conclusion. Each result fell in the range 55 to 97 ppm which is well below the specification maximum of 150 ppm and the solubility limit of about 300 ppm. The bolt material is, therefore, considered sound with respect to microstructure and hydrogen content.

Examination of the thread contour on these bolts revealed no evidence of roll forming. Subsequent inquiries into the manufacturing procedure indicated that thread grinding was used. Sample No. 2559 in Figure 2 is characteristic of the thread contour found in the five examined bolts. The lack of grain distortion around this contour is obvious. Sample No. 2525 in Figure 2 was obtained on an identical bolt from a different manufacturing lot. The threads shown here have been formed by rolling and the picture can be used for comparison purposes. At the time of purchase the manufacture of the subject bolts was not covered in any WANL specification. This situation has been remedied and the manufacture of these and all other titanium alloy bolts is presently outlined in WANL PDS 30042 which requires thread rolling.

A large amount of experimental work has been reported in the literature showing that the cold work produced at the thread notches during rolling improves the mechanical properties of most bolting materials. This is especially true when fasteners are subjected to cyclic loads where residual surface compressive stresses and increased surface strength generally result in improved fatigue properties. Thread grinding rather than rolling, therefore, may have seriously lowered the fatigue resistance of these bolts.

The above remarks assume that cyclic loading played an important part in the ultimate mode of failure. This is supported somewhat by the examination of large partially propagated cracks which were characteristic of fatigue fissures in that no metal deformation occurred around them, and they propagated in a transgranular manner. The photomicrographs in Figure 3 give examples of this. This conclusion is also supported by the results generated during reactor inspection after testing when it was established that wearing had occurred at the mating flange

area of the core support plate and the simulated core support ring*. Wearing would result in relief of the pre-load applied to the bolts in assembly causing them to flex with the applied vibrations and fail in fatigue.

Very high magnification metallographic examination of the electroless nickel-titanium interface revealed short cracks in the order of 0.0001 to 0.0005" long extending into the titanium. (Refer to Figure 4.) On two of the five examined bolts this cracking was extensive and occurred at the sides as well as the roots of the threads. It is possible that these cracks resulted from thermal shock during thread grinding and some of them provided the nucleus for propagation of fatigue cracks. These fissures may have occurred during vibration testing, but their location at sides of the threads as well as the roots, and the fact that they do not propagate through the brittle electroless-nickel layer imply their presence prior to testing. Unused bolts from the same part lot were not available for examination so that this conclusion could not be absolutely established. A close look at photomicrographs A and B in Figure 4 shows cracking to occur through or adjacent to globular precipitate clusters. Thermal shock failures would be expected to occur at these regions due to the different conductivity and expansion characteristics of matrix and precipitate. This relationship of fissure and precipitate was, however, not found in all cases as exemplified by photomicrographs C, D and E in Figure 4.

An electroless nickel-titanium interaction zone can be seen in all of these photomicrographs. Reaction must have resulted from the 500 °F bake applied after electroless nickel plating. Very minute, almost unresolvable, globular precipitates are found in this zone (most apparent in photomicrograph C). This is not unusual since the titanium-nickel phase equilibrium system contains at least three known Ni_xTi_y intermetallic compounds. Because of this, however, the zone is undoubtedly brittle which reflects a potential decrease in fatigue strength. In general, the presence of thermal shock fissures and the definite occurrence of a plating-titanium reaction layer would be expected to substantially decrease the material's resistance to fatigue.

*WANL Mechanical Design Memo 41:41:01-22L, F. G. Tauch, December 6, 1963.

CONCLUSIONS

- 1) Roll forming was not employed in threading the titanium alloy bolts which failed in vibration test ND 20101.
- 2) The bolts were not embrittled by an excessive hydrogen content, and the material appeared sound from a microstructural standpoint.
- 3) The bolts failed under cyclic loading* due to fatigue.
- 4) Thread grinding is believed to have resulted in short thermal cracks which lowered the fatigue resistance of the bolts.
- 5) A surface electroless nickel-titanium reaction zone resulted due to heat treatment following plating. Precipitates, deduced to be the $Ni_x Ti_y$ type, are apparent in this zone which undoubtedly resulted in surface brittleness and attendant loss of fatigue life.

*Cyclic loading was due to flange wear and subsequent relief of the bolt assembly pre-load.

SAMPLE NO. 2558

EQUIAXED ALPHA

100X

SAMPLE NO. 2557

EQUIAXED ALPHA + TRANSFORMED
BETA

100X

SAMPLE NO. 2559

EQUIAXED ALPHA

100X

Figure 1 - Microstructure of Bolt Material

SAMPLE NO. 2559

CONTOUR OF THREAD ON RUPTURED BOLT

50X

SAMPLE NO. 2525

CONTOUR OF ROLLED THREAD

50X

Figure 2 - Microstructures of Thread Contour of Failed Bolt
and Roll Threaded Bolt

SAMPLE NO. 2557

1500X

SAMPLE NO. 2561

1500X

SAMPLE NO. 2557

1500X

Figure 3 - Large Transgranular Bolt Cracks

SAMPLE NO. 2560 (A)

1500X

SAMPLE NO. 2557 (B)

1500X

SAMPLE NO. 2558 (C)

1500X

SAMPLE 2560 (D)

1500X

SAMPLE NO. 2557 (E)

1500X

Figure 4 - Photomicrographs of Titanium-Electrodeposit Interface Area