UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Mechanical Engineering

CREEP ASSESSMENT OF OVERHEATED GRADE 9Cr STEELS FOR DECISION MAKING ON PLANT INTEGRITY

Ng Guat Peng

Doctor of Engineering

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NG GUAT PENG

A thesis submitted
In fulfillment of the requirements for the degree of Doctor of Engineering

Faculty of Mechanical Engineering

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2014

DECLARATION

I declare that this thesis entitled “Creep Assessment of Overheated Grade 9-Cr Steels For Decision Making On Plant Integrity” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature	:	…………………………………………
Name	:	…………………………………………
Date	:	…………………………………………

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Doctor of Engineering.

Signature : …………………………………………

Name Supervisor : …………………………………………

Date : …………………………………………

DEDICATION

To my beloved mother, madam Chua Nui Poey, beloved father, Mr Ng Tiow Hock, husband, Mr Leong Chee Kian and sons, Leong Xu En and Leong Xu Zhe.

ABSTRACT

Alloy steels Gr. 91 (9Cr1MoVNb) and Gr.92 (9Cr0.5Mo1.8WVNb) are commonly used to construct supercritical and ultra supercritical boilers. The martensitic properties of both alloys require post weld heat treatment (PWHT) as mandatory process after welding. In the past experience at TNB power plants, overheating incidents had occurred during post weld heat treatment due to unintentional factors. The soaking temperature which is supposed to be controlled at 730°C to 770°C was accidentally overshot to beyond Ac_1 (800°C~830°C) and Ac_3 (890°C ~ 930°C). The overheated alloys experienced microstructure transformation which would have changed the hardness property and the creep strength of the alloys, making them unfit for further service. According to standard practice, the overheated components should be replaced immediately. Nevertheless, power station management, sometimes, encounters dilemma due to lack of time allowance to extend outages for further repair work. For this reason, the re-use of overheated components on temporary basis has become an important option to protect the national interest. This research is designed with the objective to gain an understanding of the metallurgical behavior of the overheated components and develop experimental creep curves as a guideline for operational decision making on this short term solution. Prior to this, TNB Research provided advices and recommendations based on practical knowledge and experience. With the presence of this research data, TNB Research can make a better judgment with a higher confidence level in problem-solving and decision making. The main purpose of this research is to investigate the microstructure transformation and creep property change as a result of possible overshoot above the normal tempering temperature (730°C-770°C) for these steels. The experimental results show that the hardness property is dependent on the type of microstructure matrix transformed at room temperature. The creep strength is proportional to the hardness property, but inversely proportional to the applied stress. As expected, the high temperature creep strength for both overheated alloys has dropped significantly as compared to the published creep master curves for new and unexposed specimens. Both Gr 91 and Gr. 92 alloys with overheated and degraded microstructure / property can be re-used for temporary service, depending on the metal temperature and applied stress level. Soft microstructure as a result of overheating at 850°C to 900°C has a very limited creep rupture time and it was considered unfit and impractical for further service, especially at design parameters for supercritical boilers, but if the parameters are compromised to subcritical level, temporary service up to 10,000 hours is possible. Hard microstructure as a result of cooling from 900°C to 1000°C shows improvement in creep life, likely attributed to tempering effect during creep exposure. The experimental creep data/curves developed for overheated Gr. 91 and Gr. 92 steels are reasonable and they are ready to serve as a reference/guideline to determine the temporary duration and operational load/stress selection. The allowance to re-use overheated components on temporary basis would have saved the downtime. Statistics from Stesen Janakuasa Sultan Azlan Shah, Manjung, the biggest coal-fired power plant in the county shows that the economic gain or return is equivalent to a few millions Ringgit Malaysia.

ABSTRAK

Aloi keluli gred 91 (9Cr1MoVNb) dan gred 92 (9Cr0.5Mo1.8WVNb) mempunyai rintangan suhu yang baik dan biasa diguna untuk membina dandang elektrik bertaraf ‘supercritical’ dan ‘ultra-supercritical’. Kedua-dua jenis aloi memerlukan rawatan haba selepas kimpalan. Pengalaman yang lepas dari stesen janakuasa TNB menunjukkan kekurangan dalam pengawalan suhu, menyebabkan suhu pada logam telah melampaui Ac_1 (800°C~830°C) dan Ac_3 (890°C ~ 930°C) secara tidak sengaja. Pemanasan secara berlebihan telah menyebabkan perubahan dalam sifat-sifat bahan, termasuk mikrostruktur, kekerasan, dan kekuatan rayapan aloi. Kod piawaian tidak menggalakkan pengunaan semula aloi-aloi yang mengalami pemanasan secara berlebihan. Namun, pihak pengurusan stesen penjanaan kadang-kadang menghadapi dilema sebabkan tempoh hentitugas tidak dapat dipanjangkan untuk kerja-kerja penyelenggaraan lanjut. Justeru, tanpa pilihan, komponen-komponen yang mengalami pemanasan pada suhu berlebihan terpaksa diguna dalam perkhidmatan seterusnya untuk melindungi kepentingan pelanggan. Penyelidikan ini bertujuan untuk memupuk pemahaman dalam bidang kajian logam bagi aloi yang mengalami kemerosotan prestasi akibat dari pemanasan berlebihan dan membangunkan data-data rayapan sebagai panduan untuk keputusan operasi dan penyelesaian berjangka pendek. Tanpa data-data penyelidikan ini, TNB Research memberi khidmat nasihat mengikut pengetahuan dan pengalaman tanpa rujukan. Penyelidikan ini amat penting untuk mencapai penilaian teknikal yang lebih tepat dengan tahap keyakinan yang lebih tinggi. Keputusan eksperimen menunjukkan kekerasan bahan adalah ditentukan oleh jenis mikrostruktur matrik pada suhu bilik selepas pemanasan. Kekuatan rayapan adalah berkadar langsung dengan kekerasan, tetapi kerkadar songsang dengan daya tegangan. Kekuatan rayapan didapati telah menurun dengan ketara bila dibandingkan dengan data-data rayapan yang diterbitkan untuk spesimen baru. Kedua-dua aloi gred 91 dan gred 92 yang mengalami pemanasan secara berlebihan boleh dipertimbangkan untuk perkhidmatan sementara waktu, bergantung kepada suhu dan daya tegangan. Secara umum, pamanasan pada 850°C to 900°C menghasilkan mikrostruktur yang lembut, hayat komponen adalah terhad dan tidak dicadangkan untuk penggunaan seterusnya, khususnya untuk paras ‘supercritical’, tetapi bagi ‘subcritical’ pada suhu dan daya tegangan yang lebih rendah, hayat komponen adalah dalam lingkungan 10,000 jam. Pamanasan pada 900°C ke 1000°C menghasilkan mikrostruktur yang keras, hayat komponen adalah lebih panjang, mungkin disebabkan oleh kesan-kesan ‘tempering’ bila terdedah kepada ujian rayapan. Data-data rayapan untuk aloi 91 dan 92 daripada eksperimen penyelidikan ini didapati munasabah dan merupakan panduan atau rujukan yang amat berguna dalam penentuan tempoh perkhidmatan berjangka pendek dan pemilihan daya tegangan yang optimum. Penggunaan semula komponen-komponen yang mengalami pemanasan pada suhu berlebihan secara tidak sengaja, sebagai penyelesaian sementara waktu, telah dapat menjimatkan ‘downtime’. Statistik dari Stesen Janakuasa Sultan Azlan Shah, Manjung, menunjukkan keuntungan ekonomi dalam lingkungan beberapa juta Ringgit Malaysia.

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LIST OF ABBREVIATIONS

APFIM	Atom Probe Field Ion Microscopy
ASM	American Society for Metals
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
BCC	Body Centered Cubic
BM	Base Metal
BSE	Back-Scattered Electron
CCT	Continuous Cooling Transformation
CGHAZ	Coarse Grain Heat Affected Zone
DOSH	Department of Occupational Safety and Health
EBSD	Electron Back-Scattered Diffraction
ECCC	European Creep Collaborative Committee
EDX	Energy Dispersive X-Ray
FCC	Face-Centered Cubic
FE-SEM	Field Emission Scanning Electron Microscope
Fe_2W	Laves Phase
FGHAZ	Fine Grain Heat Affected Zone
Gr.	Grade
HAZ	Heat Affected Zone
HV	Hardness Vickers
ICHAZ	Intercritical Heat Affected Zone
IGCAR	Indira Gandhi Centre for Atomic Research

IPP	Independent Power Producer
KEPRI	Korea Electric Power Research Institute
LMP	Larson Miller Parameter
Max.	Maximum
Min.	Minimum
MnS	Mangenese Sulphide
MPa	Mega Pascal
MW	Megawatts
NbC	Niobium Carbide
NbN	Niobium Nitrate
NIMS	National Institute for Material Sciences
OM	Optical Microscope
ORNL	Oak Ridge National Laboratory
PAGB	Prior Austenite Grain Boundaries
PM	Parent Metal
PPTs	Precipitates
PWHT	Post Weld Heat Treatment
QATS	Quality Assurance and Testing Services
SC	Supercritical
SE	Secondary Electron
SJSAS	Stesen Janakuasa Sultan Azlan Shah.
SJTJ	Stesen Janakuasa Tuanku Jaafar.
TEM	Transmission Electron Microscope
TiC	Titanium Carbide
TiN	Titanium Nitrate
TNB	Tenaga Nasional Berhad
TNBJ	TNB Janamanjung
TNBR	TNB Research Sdn. Bhd.
USA	United States of America

USC	Ultra-Supercritical
VC	Vanadium Carbide
VN	Vanadium Nitrate
V & M	Vallourec & Mannesmann
WM	Weld Metal

LIST OF SYMBOLS

A	-	A constant for Power Law
Ac_1	-	Lower Critical Transformation Temperature
Ac_3	-	Upper Critical Transformation Temperature
a	-	Crystal lattice of unit cell
α-ferrite	-	Alpha Ferrite
α ‘	-	Martensite
b	-	Burgers vector length
CO_2	-	Carbon Dioxide
d	-	Particle mean size
d_0	-	Initial particle size
δ-ferrite	-	Delta ferrite
ε	-	Creep strain
ε_F	-	Strain to failure
έ	-	Creep strain
$έ_s$	-	Steady state creep rate
G	-	Shear modulus
g	-	Gram
γ-austenite	-	Gamma Austenite
h	-	Hour
K	-	Dimensional constant
k	-	Boltzmann’s constant
k	-	Particle growth rate