1. **Project Name:**
Fracture Toughness and Strength in a New Class of Bainitic Chromium-Tungsten Steels

2. **Lead Organization:**
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3. **Principal Investigator:**

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4. **Project Partners:**

? Nooter Fabrication Services Inc., **In-Kind**, provided technical requirement and review for the processing and application of the materials as well as welding process technology.
Contact: Maan Jawad, Tel: (314) 421-7339 Fax: (314) 421-7704

5. **Date Project Initiated and FY of Effort:** 10/1/2001; FY03

6. **Expected Completion Date:** 09/30/2004

7. **Project Technical Milestones and Schedule:**
The research objective of this project is to understand how to control the composition and heat treatment to achieve high strength and toughness for developing a new class of Fe-3Cr-3WV(Ta) steels for large chemical process equipment applications.

Description	Completed Date	Planned Completion Date
1. Steels samples Preparation	Oct. 2001	Oct. 2001
2. Microstructures observation by TEM	Mar.2002	Mar.2002
3. Investigation of carbides within the steels by TEM using extraction replicas samples	Jun. 2002	Jun. 2002
4. Fracture toughness testing of 3Cr-3VW steels	Sep. 2002	Sep. 2002
5. Effects of aging at 550°C on microstructure, hardness and fracture toughness of the steels.	Mar.2002	Mar.2002
6. Observation of microstructures of the new bainitic Fe3Cr alloy steels		Jun. 2003
7. Fracture toughness testing of Fe3Cr alloy steels		Sep. 2003

8. Microstructure observation of welded joint of the 3Cr-3VW(Ta)		Dec. 2003
9. Fracture toughness testing of welded joint of 3Cr-3VW steels		Mar. 2004
10. Effects of past-weld heat treatment (PWHT) on the microstructure, hardness and fracture toughness of the welded joint of 3Cr-3VW(Ta) steels.		Aug. 2004
11. Summary of the project		Sep. 2004

8. **Past Project Milestones and Accomplishments**:

1. High strength and toughness steels of 3Cr-3WV have been developed at the Oak Ridge National Laboratory (ORNL). The 3Cr-3WV(Ta) steels has strength as good as or higher than those of 2.25Cr-1Mo steel (T22) approved in the ASME Code as 2.25Cr-1.6WVNb (T23) and 9Cr-2WV(Ta) steels.
2. Based on 3Cr-3WV steels, recently a new steel of Fe3Cr alloy has been developed at the Oak Ridge National Laboratory (ORNL). The impact properties of the steel were remarkably improved by adding small amount of Ni and Mo into the steel.
3. The microstructures of the 3Cr-3WV and 3Cr-3WVTa steels under normalized and normalized-and-tempered conditions have been examined by optical microscope (OM) and transmission electron microscope (TEM). The results showed that both the 3Cr-3WV and 3Cr-3WVTa steels have the microstructure of acicular bainite. Addition of Ta into 3Cr-3WV steel can substantially decrease the prior austenite grain size, but the effect on bainite packet size is not as significant.
4. Carbides, especially fine TaC particles, precipitated in the steels have been extensively examined by TEM with extraction replicas samples. Addition of Ta into 3Cr-3WV steel can also substantially decrease the carbides size precipitated and separated in the grains and particularly the size of carbides at prior austenite grain boundaries.
5. Tensile test and fracture toughness (K_{1C}) test have been carried out. The 0.2% yield strength and fracture toughness of 3Cr-3WVTa steel are higher than those of 3Cr-3WV steel, especially under the normalized-and-tempered condition.
6. Aging of the steels at 550^{o}C for up to 1000 h has been performed, and the effects of aging on the microstructure and fracture toughness have been investigated. Aging has less influence on fracture toughness of both the normalized and normalized-and-tempered steels.
7. Effects of fine carbides in the steels on strength and fracture toughness of the steels have been studied. The 3Cr-3WV(Ta) steels are mainly strengthened by secondary-phase precipitation mechanisms by fine carbides formed after tempering.

9. **Planned Future Milestones:**

? A new bainite Fe3Cr alloy steel, which is a modification on the basis of 3Cr-3WV steel, has been recently developed in Oak Ridge National Laboratory. (Apr.2003)
? The microstructures of the new bainitic Fe3Cr alloy steels under normalized and normalized-and-tempered conditions will be examined. (Jun.2003)
? Fracture toughness K_{1C} of the new Fe3Cr steel will be measured and The fractographs of the Fe3Cr steels will be observed by SEM. (Sep.2003)

- The microstructures of welded joint of the 3Cr-3VW(Ta) steels will be examined.(Dec.2003)
- Hardness distribution across the weld line and fracture toughness K_{1C} of weld metal and HAZ of welded joint of the 3Cr-3VW(Ta) steels will be determined. (Mar.2004)
- The effects of PWHT on the microstructure, hardness and fracture toughness K_{1C} of the welded joint of 3Cr-3VW(Ta) steels will be studied. (Aug.2004)
- Summary of the project. (Sep.2004)

10. **Issues/Barriers:**

- There are no significant barriers encountered so far in investigation of composition, microstructure, heat treatment and mechanical properties relationship of the new bainite 3Cr-3WV(Ta) steels.

- The effects of aging on the microstructure and fracture toughness have been investigated, which was not the part of the original scope. Such deviation was adopted due to requirements of industrial applications.

11. **Intended Market and Commercialization Plans/Progress:**

- The results will provide an understanding of the relationship among composition, microstructure and heat treatment to achieve both high strength and fracture toughness, and guide the development of a new class of Fe-3Cr-W(V) ferritic steels.
- High strength and fracture toughness 3Cr-3WV(Ta) steels can be used in chemical engineering equipment, large pressure vessel and associated components.
- The weight of steels for construction of those components will be expected to be reduced by approximately 25% by using new 3Cr-3WV(Ta) steels.
- The elimination of PWHTs of components may provide extensive energy savings.

12. **Patents, publications, presentations:**

(1) Fine Carbides Strengthened 3Cr-3WVTa Bainite Steels,
Zheng Chen, Zhi-wei Shan, N. Q. Wu, V. K. Sikka, Mingjian Hua and Scott X. Mao,.
(*Materials Science & Engineering A*, acceptable for publication with requirement of revision, Jan.17, 2003)

(2) Fracture Toughness and Strength in a New Class of Bainitic Chromium-Tungsten Steels, Mao, S. & V. Sikka, Industrial Materials for Future (IMF) Program Review Meeting, Albuquerque, NM 87102, July 8-10, 2002.

(3) Effect of aging on microstructure and fracture toughness of 3Cr-3VW(Ta) steels
Zheng Chen, Zhi-wei Shan, N. Q. Wu, V. K. Sikka, and Scott X. Mao,
(to be submitted *to Mat. Sci. & Eng. A*)

Highlight

Significant Results Achieved:

? Addition of Ta into 3Cr-3WV steel can substantially decrease the prior austenite grain size, but the effect on bainite packet size is not as significant.

? Fine TaC precipitates were formed in normalized 3Cr-3WVTa specimen, whereas no precipitates could be detected in 3Cr-3WV steel after normalizing.

? After tempering of 3Cr3WVTa steel, fine TaC particles were further precipitated and separated within the grains and particularly the size of carbides at prior austenite grain boundaries was smaller than that in the 3Cr-3WV steel.

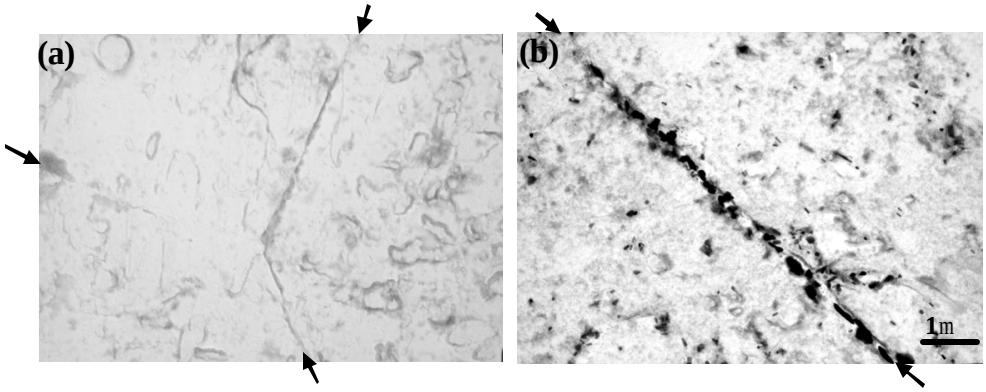

Fig.1. TEM micrographs of extraction replicas of (a) normalized 3Cr-3WV steel and (b) normalized-and tempered 3Cr-3WV steel. (prior austenite grain boundaries are indicated by arrows)

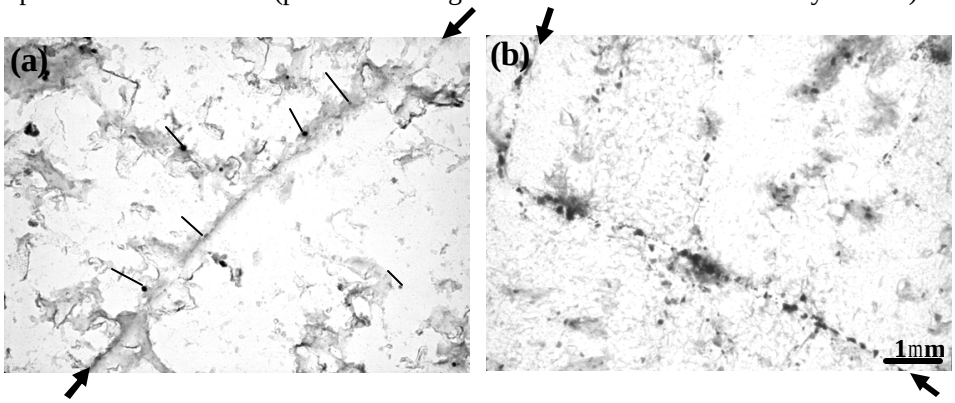

Fig.2. TEM micrographs of extraction replicas of 3Cr-3WVTa steel. (a)normalized and (b) normalized-and-tempered. (prior austenite grain boundaries and TaC carbides are indicated by large and small arrows, respectively)

? The 3Cr-3WVTa steel were mainly strengthened by secondary-phase precipitation mechanisms by fine carbides formed after tempering.

? The 3Cr-3WV(Ta) steels has strength as good as or higher than those of 2.25Cr-1Mo steel (T22) approved in the ASME Code as 2.25Cr-1.6WVNb (T23) and 9Cr-2WV(Ta) steels.