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Effect of Carburization on Toughness and Ductile-Brittle Transition Temperature for Cr-Mo grade material

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ABSTRACT: *The heater tubes made of Cr-Mo steel, due to their excellent mechanical and corrosion resistance properties at higher temperature are widely used in petroleum refineries to increase the temperature of reduced crude oil in a coking or breaking unit. These process tubes are subjected to severe operating conditions in terms of temperature and nature of feed handled. The tubes generally tend to fail by creep or corrosion or a combination of the two. Environmental reaction such as carburization can embrittle tubes and reduce creep strength and fracture toughness.*

Keywords: *Delayed Coker Unit (DCU), Ductile Brittle Transition Temperature (DBTT), Fractography, Fracture Toughness, Instrumented Charpy Test.*

I. INTRODUCTION

The process heater tubes in petroleum refinery are used to increase the temperature of reduced crude oil to a specified level (around 500ºC) required in a coking or breaking unit. These tubes are externally oil/ gas fired and crude flows internally at a given pressure. Hence, these process tubes are subjected to severe operating conditions in terms of temperature and nature of feed handled. Cr-Mo steels are widely used due to their excellent high temperature creep strength and resistance against oxidation. Cr- Mo steel has high strength and high toughness properties [1]. Heavy carbon residues passes through heater tubes made of Cr-Mo steel at high temperature above 500^{0}C. Typically the diameter of tube is around 100mm-140mm. In the heating process, diffusion of carbon takes place from heavy carbon residues to the parent material. Due to this carburization, degradation of mechanical properties occurs. Another effect is the formation of coke layer inside walls of these heater tubes. During service at elevated temperatures these pipes did not show any kind of defects but during the maintenance in the process of removal of scale by hammering brittle cracks developed throughout the pipe length even though they were at ambient temperatures. Here mainly the material toughness and its degradation in service are considered as limiting factor. Hence generation of fracture toughness data and its degradation with service is of prime importance.

The broad objectives of this work are as follows:

(a) Determination of Fracture Toughness and Ductile Brittle Transition Temperature (DBTT) of Virgin Material (T9) by using notched standard Charpy specimens in Instrumented Charpy Test.

(b) Comparison of fracture toughness and DBTT of both the virgin and service exposed materials.

II. METHODOLOGY/EXPERIMENTAL

DCU heater tube of one of the Refinery was removed from service after a service period of 8 years. One such tube was used for this work. A virgin tube of same metallographic was also used in this work. The operational Parameters are given in the following Table 1.

Table 1: Operational Parameter

Material	**T9 (9Cr-1Mo)**
Tube metallurgy	ASTM A335 T9
Nominal wall thickness of tube	11mm
Outer diameter	140mm
Intel Design Pressure(kg/cm^2)	65
Intel Operating pressure(kg/cm^2)	50
Intel and Outlet Design Temperature(ºC)	612
Intel Operating Temperature(ºC)	373
Outlet Operating Pressure(kg/cm^2)	4
Outlet Operating Temperature(ºC)	498

The experiments were performed on Zwick Instrumented Charpy Machine (Zwick/Roell, RKP 450). The Instrumented Charpy Machine is the advanced version of Conventional Charpy Machine [2]. Instrumented Charpy tests were done on notched standard Charpy specimens prepared as per ASTM E23 [3] shown in the Fig. 1. Experimental results obtained are shown in Table 2 and they are plotted in Fig. 2.

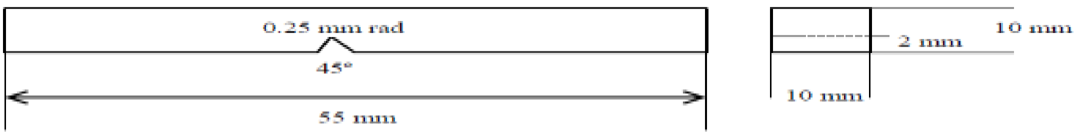


Fig. 1: Standard Charpy Specimen as per ASTM E23

III. RESULTS

Table 2: Experimental Results for Notched Specimens (Impact Energy, CVN (J))

Temperature (ºC)	**Service Exposed Specimens Toughness**	**Virgin Specimens Toughness**
60	242.67	210.60
25	211.17	208.90
0	142.86	149.29
-20	117.87	127.80
-40	14.60	95.50
-50	10.50	78.65
-80	7.94	14.67
-100	7.8	14.86

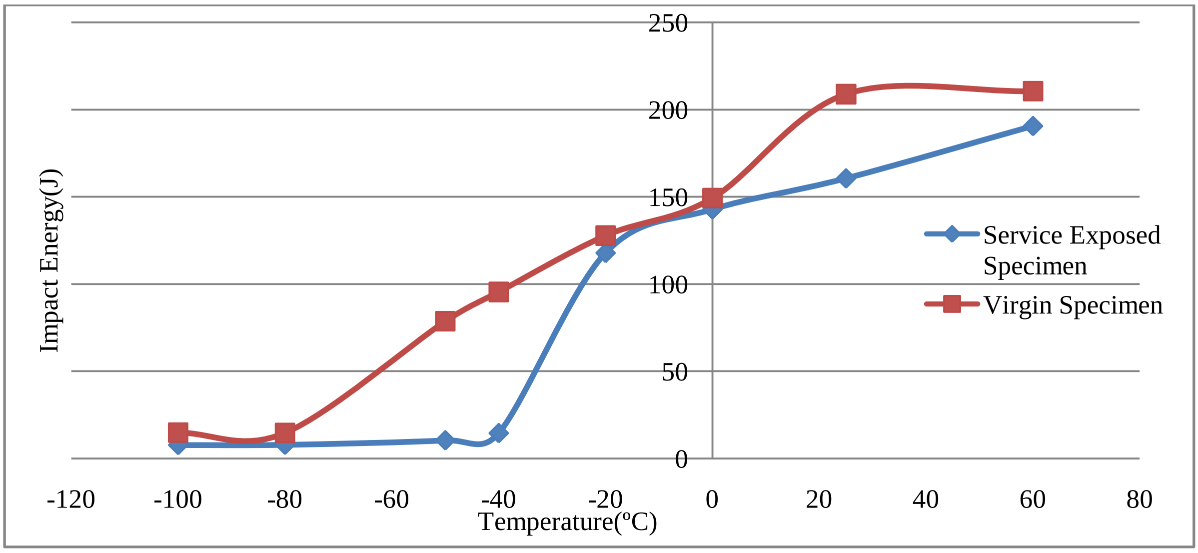


Figure 2: Impact Energy vs. Temperature

DBTT is defined as the temperature corresponding to average of upper shelf energy and lower shelf energy [4]. These results are compared in the following table.

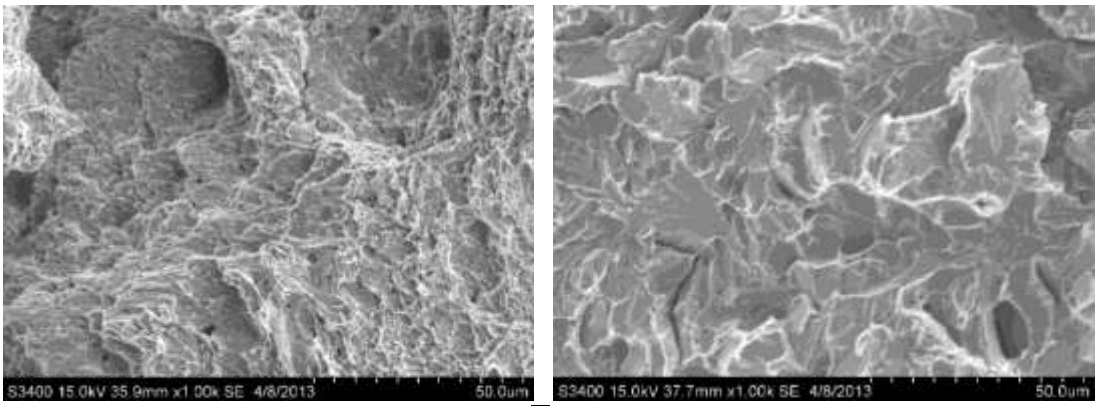
Table 3:

T9 Material	Impact Energy(J) at room temperature	DBTT (ºC)
Virgin specimen	208.90	-38
Service exposed specimen	160.60	-25

IV. DISCUSSION

The Charpy impact test for service exposed material exhibit sudden change in impact energy of 100 to 105J at DBTT, which is higher as compared to change in impact energy of virgin material (35 to 40J). The DBTT of service exposed material has been obtained as -25ºC against -38ºC of virgin material. This indicates service expose to carbon atmosphere leads to diffusion of carbon, has changed the impact properties as well as increase in DBTT.

Fractured surface was metallographically prepared and observed in scanning electron microscope (SEM). Fractured surface of service exposed material at room temperature and DBTT is shown in the Fig. 3.



(A)Room Temperature (25ºC)

(B)DBTT (-25ºC)

Fig. 3: Fractured Surface of Service exposed material

V. CONCLUSION

The following conclusions are drawn:

1. As a result of carburization of T9 steel, impact properties changed to a great extent and DBTT got shifted to a much higher value.
2. Fractography of service exposed material at room temperature shows dimples like structure, it indicates that fractured surface is of ductile in nature and at DBTT has cleavage like structure consisting of plane surface patterns and river patterns (Brittle failure).

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