Delayed fracture on self-tapping screws

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Abstract

Hydrogen induced fracture on two different screw stocks (UNI C16 modified and UNI C23BKD) was analysed.
Fracture toughness has been evaluated by area reduction measurements carried out on carbonitrided specimens, fractured by tensile test, and rupture angle measurements on specimens broken by torsion tests.
Specimens were cathodically charged with hydrogen (current density = 10 mA/cm²).

Riassunto

È stata studiata la frattura differita indotta dall'idrogeno su due differenti acciai per bulloneria (UNI C16 modificato e UNI C23BKD).
La tenacità alla frattura è stata valutata mediante misure di riduzione d'area condotte su provini carbonitrurati, rotti a trazione, e mediante misure dell'angolo di rottura su provini rotti a torsione.
I campioni sono stati caricati catodicamente con idrogeno (densità di corrente = 10 mA/cm²).

INTRODUCTION

In this work we report the results of a specific research about delayed fracture.
In particular, this research is motivated on the observation of several events of delayed fracture of self trapping screw, during working conditions.
Generally, these components are realised with Ni-Cr steels or boron steels; boron is widely used to increase hardenability, since a few ppm (10 - 30 ppm in weight) of boron result in very large effects on this property [1-4].
The screws examined were realised with a low carbon steel (UNI C16 modified) and successively carbonitrided and quenched; after these treatments the microstructure became very sensitive to the hydrogen induced fracture [5-9].
Since the final step of the production run of the screw is a cold galvanising treatment, it is during this one that hydrogen penetrates into the screw, making it brittle [10].
This problem is partially solvable heating the screws at 150°C after zinking, in order to favour the hydrogen degassing; nevertheless this treatment is not economically profitable.
Since in a previous work in course of publications [11] we have studied the positive effect of the boriding thermochemical treatment on hydrogen induced fracture, with this work we want to verify if boron can eventually improve the toughness of the screws with regard to delayed fracture induced by hydrogen.
To this purpose, the screws were realised with a steel containing boron (UNI C23BKD) and it has been possible to observe a real better behaviour in working conditions.
In order to understand the mechanisms that cause this improvement, specimens realised with the two different steels, were subjected to hydrogen embrittlement tests.
Embrittlement degree was evaluated by area reduction measurements on samples subjected to tensile tests and by rupture angle measurements on samples subjected to torsion tests.

EXPERIMENTAL PART

Chemical composition of the steels used for the tests are reported in Table 1.
All the samples were subjected to carbonitriding thermochemical treatment; the parameters relative to the treatment are reported in Table 2.
The steels were characterised by means of two different testing methods:

- tensile test at variable load
- torsion test.

In the first case, the embrittlement degree was evaluated by means of area reduction measurements with the following formula:

$$RA_{loss} = \frac{RA - RA_H}{RA} \cdot 100$$

where RA and RA_H are respectively area reductions, i.e. the difference between nominal section and final section after test, of the samples uncharged and charged with hydrogen.

TABLE 1 - Chemical composition of the steels used (wt. %)

	C	Cr	Ni	Mn	Si	B	Al	Cu	S	P
C16	0,18	0,03	0,02	0,66	0,30	-	0,048	-	0,006	0,007
C23BKD	0,22	0,03	-	0,63	0,02	0,003	0,033	0,038	0,012	0,015

TABLE 2 - Parameters of the carbonitriding thermochemical treatment

	TG80/54Ti (N)	**05.02.97 10:40:29**
PARAMETERS DENOMINATION	REQUEST VALUES	REAL VALUES
TREATMENT PROGRAM	1	
INPUT ZONE TEMPERATURE	880°C	879°C
INTERMEDIATE 1 TEMPERATURE	910°C	911°C
INTERMEDIATE 2 TEMPERATURE	880°C	884°C
OUTPUT ZONE TEMPERATURE	860°C	866°C
GAS INJECTION TEMPERATURE	980°C	985°C
OIL TEMPERATURE	65°C	66°C
TREATMENT TIME	25 MIN	25.0 MIN
AGITATOR RATE	800 T/MIN	800 T/MIN
LOAD	33 Kg/H	
AMMONIA FLOW	270 L/H	282 L/H
% CARBON "SCR" T2	1.10 %	1.15 %
% CARBON "SCR" T3	0.90 %	0.90 %
PROBE TEMPERATURE T2........T3		876°C 865°C
AIR FLOW T2.........T3		OL/H OL/H
PROPANE FLOW T2.........T3		73L/H 89L/H

During the tests at variable load, the feed speed of tensile test machine cross-bar was 0,05 mt/sec; this value was chosen just to emphasise hydrogen embrittling effect instead of mechanics tensile one on failure mechanism.
About the torsion tests, the measurement of the rupture angle was considered as index of the embrittlement degree.

Figs. 1 and 2 show the sample geometry and dimensions respectively of the tensile test sample and the torsion test one. Hydrogen was introduced into the samples in intensiostatic conditions (the current density value was 10 mA/cm^2) by means of cathodic charge, using a solution 0,1 N of H_2SO_4.

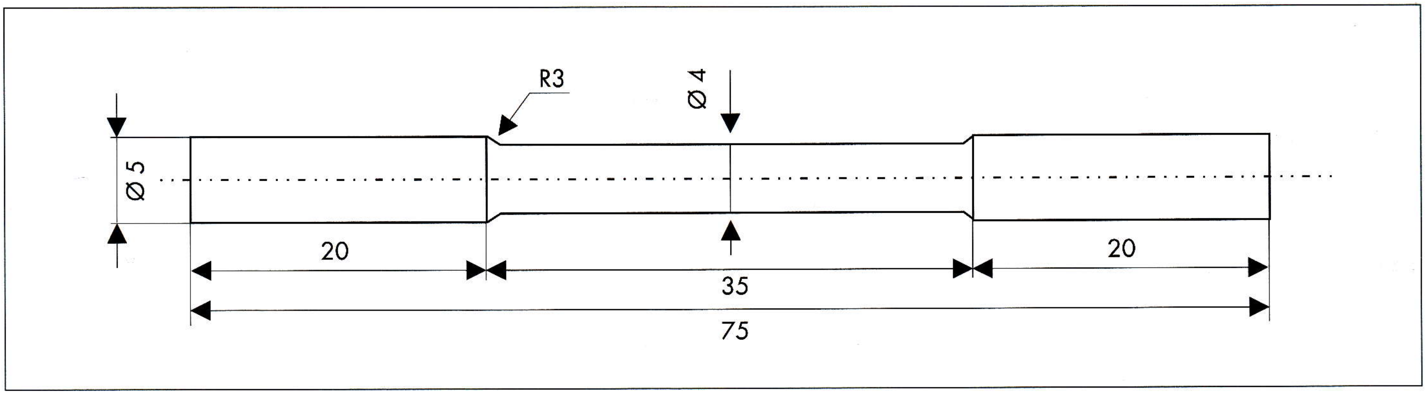

Figure 1: Geometry and dimensions (in millimetres) of the tensile test specimen

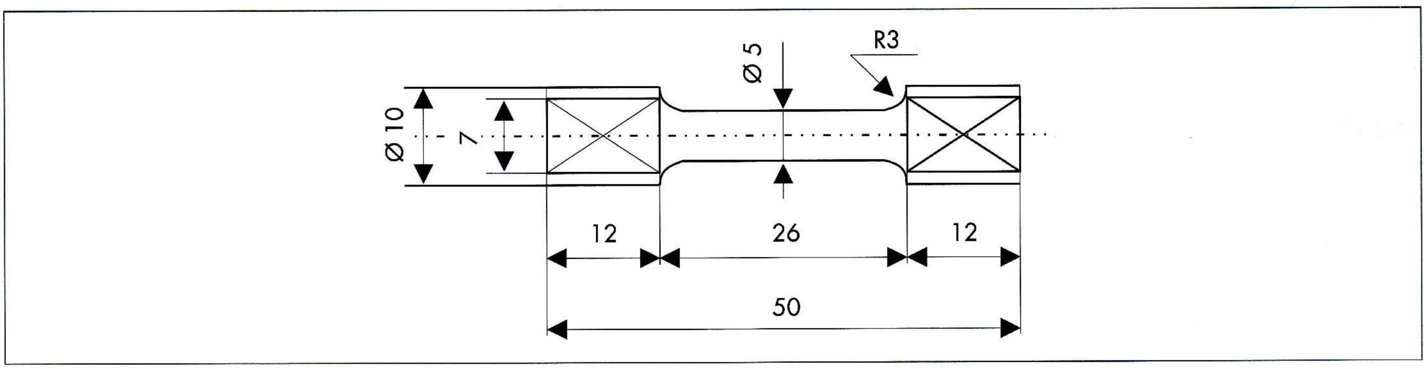

Figure 2: Geometry and dimensions (in millimetres) of the torsion test specimen

RESULTS AND DISCUSSION

The results of the tensile tests and the area reduction measurements carried out on the specimens realised with the two different steels used in this work, are reported in Table 3 and in Table 4.

TABLE 3 - Chemical composition of the steels used (wt. %)

steel	specimen condition	hydrogen charging time (hours)	percent elongation at rupture	RA%
C16	carbonitrided	no	14,0	65,0
	carbonitrided	1	12,8	59,5
	carbonitrided	4	10,8	51,8
	carbonitrided	8	11,3	52,0

TABLE 4 - Results of the tensile tests on UNI C23BKD steel specimens

steel	specimen condition	hydrogen charging time (hours)	percent elongation at rupture	RA%
C23BKD	carbonitrided	no	14	75
	carbonitrided	1	12,5	72
	carbonitrided	4	13,5	71
	carbonitrided	8	13,0	71,5

The results obtained by the torsion tests are reported in Table 5 and in Table 6 respectively for UNI C16 steel and UNI C23BKD one.
As it is possible to observe from area reduction values obtained by the tensile tests, the specimens realised with boron steel show a lower loss of ductility if compared with the data obtained by UNI C16 steel (without boron); this fact confirms the better behaviour to fracture of the boron steel in comparison with the other one.
Also from examination of the values of the torsion angles measured by means of the torsion tests, nearly equal to each other for the different charging times, it is clear that boron steel toughness is not affected by the amount of hydrogen, that interacts with the material.
This behaviour was attributed to the interaction between the hydrogen, carried by the dislocations, which are put in motion during the plastic deformation, and boron compounds present inside the carbonitrided layer.
In fact, some authors [12-16] have verified, with the aid of very advanced techniques, that boron, during heat treatments, forms complex phases with the metal elements present as alloying element in very small quantitative.
It is possible to suppose that these phases, by trapping the hydrogen on the carbonitrided surface, slacken considerably its diffusion into the zone not interested by the carbonitriding superficial treatment.
In these conditions, the embrittling action of the hydrogen affects exclusively the superficial layer and does not reach the internal zone of the sample.
This fact is confirmed by the fractographic analysis of fracture surfaces.

TABLE 5 - Results of the torsion tests on UNI C16 steel specimens

steel	specimen condition	hydrogen charging time (hours)	ultimate torque (Nm)	deformation angle (degree)
C16	carbonitrided	no	40	55
	carbonitrided	1	42	53
	carbonitrided	4	41	50
	carbonitrided	8	41	46
	carbonitr. galvanized	no	40	55
	carbonitr. galvanized	1	43	48
	carbonitr. galvanized	4	42	50
	carbonitr. galvanized	8	42	40

TABLE 6 - Results of the torsion tests on UNI C23BKD steel specimens

steel	specimen condition	hydrogen charging time (hours)	ultimate torque (Nm)	deformation angle (degree)
C23BKD	carbonitrided	no	40,0	56
	carbonitrided	1	40,6	63
	carbonitrided	4	38,8	57
	carbonitrided	8	37,9	56
	carbonitr. galvanized	no	39,8	60
	carbonitr. galvanized	1	39,3	54
	carbonitr. galvanized	4	38,9	60
	carbonitr. galvanized	8	38,3	47

Fractographic analysis

Fractographic analysis was executed by the SEM (Scanning Electron Microscope) immediately after the rupture of the specimens, in order to avoid superficial oxidation, that should make impossible any observation.
Figs. 3 and 4 show respectively fracture surfaces of UNI C16 steel specimen and UNI C23BKD steel one.
It is possible to observe how the surface of the sample realised with UNI C16 steel and carbonitrided, is characterised by a predominantly intergranular morphology typical of the brittle fracture, interesting the whole section of the specimen.
By the analysis of fracture surface of UNI C23BKD steel sample, it can be observed that the brittle fracture is limited exclusively to the carbonitrided layer, while the internal zone shows a ductile rupture, with microvoids coalescence.

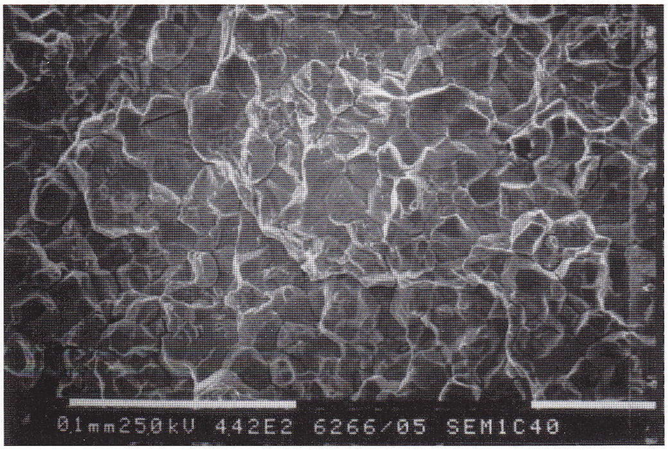

Figure 3: Fractograph of carbonitrided UNI C16 steel specimen

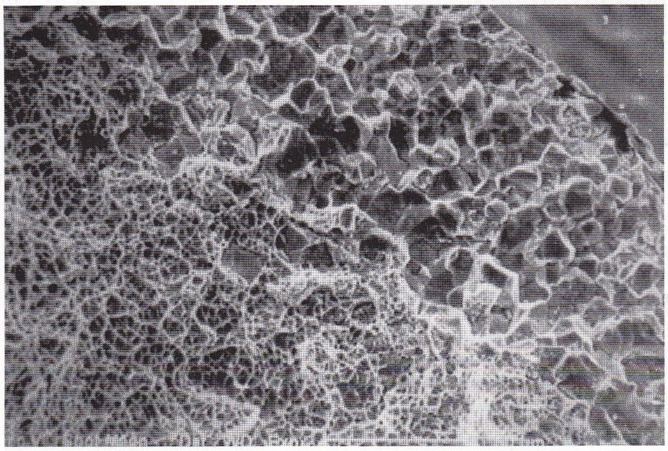

Figure 4: Fractograph of carbonitrided UNI C23BKD steel specimen

CONCLUSIONS

The better behaviour of boron steel, verified by mechanical tests and fractographic analysis, was attributed to a possible role of borocarbides present inside the carbonitrided layer as traps for hydrogen [17,18], carried by the dislocations, during the plastic deformation.
The results obtained by these tests are in agreement with other ones reported in a previous work in course of publication [11], in which the effects of boriding thermochemical treatment with regard to delayed fracture induced by hydrogen were studied.
This thesis is confirmed and strengthened by fractographic analysis; in fact the UNI C16 steel (without boron) shows a brittle fracture morphology, while the UNI C23BKD boron steel presents a brittle rupture limited to the carbonitrided zone, and a ductile fracture, with microvoids coalescence, in the internal zone of the material.

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