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Evaluation of New Tool Joint Hardfacing Material for Extended Connection Life and Minimum Casing Wear

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ABSTRACT

New wear resistant materials for hardfacing of tool joints hwre been developed and were successfully tested under relevant conditions at the Institute of Petroleum Engineering (ITE) of the Techn. Univ. Clausthal, Germany.

out of a total of eight new products two combinations of hardmaterial and bond were very positive with respect to following two criteria;

- low wear figures for the protected tool joint in very abrasive formations and
- low casing wear due to axial and rotating interaction of the protected tool joint under radial loads (5-1/2" tool joint in 9-5/8" casing Grade C-90)

The new products show drastic improvements with respect to earlier results under similar test conditions.
Results are presented in OD-wear of tool joint and reduction of wall thickness of casing material with respect to distance slid, i. e. in pm/km.
A new testing facility allowing a combination of axial movement and rotation was used. Beside casing material Grade C-90 abrasive Silicon Carbide (SiC) material shaped to 8-1/2" borehole contour with a contact length of 10 inch were used.

IIMODUCTION

The tool joints on drill pipe are subjected to wear in the borehole and can be successfully protected by hardfacing. In deviated boreholes, however, the tool joint may cause severe wear on the inside of the casing during drilling and tripping. Hardfacing of tool joints, as used in the past, contributed to accelerated casing wear. For more than fifteen years, extensive progress has been made with the hardfacing technique. This improved hardfacing technique must achieve the following two objectives:
- extended life of the tool joint, and - reduced wear on casing.

The first requirement may be termed the passive wear characteristic of the hardfacing, and the second the active wear characteristic of the tool joint'.
Great effort has been devoted to hardfacing and the evaluation of the various hardfacing techniques in numerous publications. In 1967, R. W. LewiS2 conducted experiments with various hardfacing materials and demonstrated that coarse tungsten carbide material in a relatively soft matrix results in the most severe casing wear, while hardfacing with fine particles and smoothing of the surface area were less detrimental. The objective of hardfacing at that time was concentrated mainly on the wear resistance of the tool joint. It was also proved that wear increases with contact pressure and rotational speed.

Intensive tests have also been performed by Bradley and Fontenot3. Among other results, it is evident from the work of these authors that the exposure of the hardfaced area severely aggravates casing damage. Their investigation of casing wear included protectors, tool joints, and wireline cables. Their results clearly show that the rotation of the drill string member is of greater importance with respect to casing wear than round trips.

The paper by True and Weiner4 was also published in 1975. They demonstrated the effects of the drilling fluid, grade of the casing material, and

References and figures at end of paper the tool joints as well as protectors. Gooch, experimented with double-layer hardfacing for reducing casing wear. Nbvig, proposed an evaluation of the efficiency of the tool joint protection with respect to its wear resistance (passive wear) and damage to casing (active wear). Williamson6 has investigated the contact pressure and showed that under high contact pressure adhesive wear also occurs, besides abrasive wear. Best7 has evaluated various fine-particle tungsten carbide types (crushed and pelletized). All authors agree that smooth hardfacing decreases casing wear, while new rough hardfacing surfaces result in high wear rates, even when the particles are small. The smoothed surface of the hardfacing should be flush with the outer tool joint diameter and secured before the application of hardfaced tool joints in cased boreholes.

In 1985, White and Dawson8 published their results on casing wear with non-hardbanded tool joints in casing of different grades with the use of four drilling f1vids. Two contact forces were applied during their experiments. They proposed a wear efficiency model defined as the ratio of energy absorbed in wear to the total mechanical energy input. The authors proved the usefulness of their model, as it allows a prediction of casing wear as well as an explanation of different wear rates under otherwise similar conditions. The advantage of the dimensionless wear efficiency is clearly demonstrated by the examples given. Without the hardness number, the wear efficiency model relates the amount of metal removed to the energy dissipated in the wear process. Such specific energy figures play an important role in the analysis of the drilling process.

Another method of predicting casing wear due to drill string rotation has been discussed by Schoenmakers9. The author comes to the conclusion that casing wear caused by rotating tool joints with hardfacing can be controlled with the use of sufficiently smooth hardfacing, weighted drilling fluid, and moderate contact forces between the tool joint and casing.

For reference, the author suggests a wear penetration within 1 mm (0.04 in) as an acceptable value. This can be maintained for a drilled interval of 1000 m (3300 ft) at a drill string rotational speed of 115 min-' and an assumed drilling speed of 5 m/h (16.4 ft/h), if

- the maximal contact force does not exceed 8 kN (1.8 kip),
- the mass content of barite in the drilling fluid is 10 per cent or higher, and
- the hardfacing is smooth.

As indicated by the author, the smoothness of the hardfacing should be measured by the contact print technique.

As one can see, the main concern was given to the casing wear and ways of reducing it for safety reasons. The objective of extending the life of the tool joint was not investigated as intensively. As new hardfacing materials now become available, it is important to check the double objective of hardfacing with respect to tool joint wear in highly abrasive formations and casing wear associated with hardfaced tool joints.

EXPERIMENTAL PROGRAH

For testing new hardfacing materials, a new machine has been designed and built; this machine allows simultaneous testing of two tool joints. The test set-up is shown schematically in figure 1. The two parallel -mounted tool joints rotate, while the casing sample (or abrasive material) is pressed against the rotating tool joints under controlled contact forces and reciprocate in parallel with the axes of the tool joints with a stroke length of 100 mm (4 in) to completely cover the hardface banding.

Clear water was chosen as circulating fluid, in order to obtain pronounced wear conditions. The water flows continuously onto the tool joint from the device for holding the casing or abrasive material, respectively. Silicon carbide grinding wheel material was chosen to simulate abrasive rock. This material is employed for dressing stabilizers and milling tools. In correspondence with the 9-5/8" casing size, the contour of the grinding wheel was cut to 8-1/2" borehole size. Four pieces of grinding wheel segments were mounted as a package 200 mm (8 in) in length. See figure 2.

The 5-1/2" hardfaced tool joints are original samples as supplied for welding onto drill pipe. The hardfacing is 100 mm (4 in) in length and flush with the outside diameter of the tool joint. The hardfacing follows the 18* shoulder by 19 mm (3/4 in). The total length of the tool joint section is 400 mm (15.75 in).

A total of eight 5-1/2" tool joints were tested with respect to both wear resistance in abrasive formations and casing wear caused by the tool joints. The hardfacing material, type 29, of Durum was used for six samples. This hardfacing material differs only with respect to particle size (20 to 60 mesh) and concentration of the cast tungsten carbide material. The hardfacing material is applied by electric welding with the use of cored wire electrodes "DURMAT" NFD containing Ni, W, Cr, Si, C, and B as elements. Another test material (R III) contains pelletized fused-cast tungsten carbide with particle sizes up to 1 mm. The electrode material is steel.

TEST PROGRAM

The test program remained unchanged for all tool joints.

Rotational speed:	n = 160 min-'
Linear velocity:	vi = 24.5 m/h (80 ft/h)
Contact force:	Fc = 4.48 kN (1 kip)
Casing material:	Segments of 9-5/8", Grade C-90

The test procedure was as follows: I.Casing contact for six hours
2. Abrasive wheel contact for seven times six hours (42 h)
3.Casing contact for six hours

Results are Presented in tabular and graphic form as wear in pm versus the number of revolutions executed; see table 1 and figure 4. In the second diagram of figure 4, the type of Presentation is the same, but the wear is plotted against the number of revolutions of the tool joint in the abrasive material and against the casing material separately.

In most cases, the wear of the tool joint against steel was of the same order of magnitude as that in the abrasive; this observation is independent of easing wear at the beginning or at the end of the test. In two cases, however, (29/1 and 32), there is a pronounced difference in the wear trend. In these cases, the wear against the abrasive material was much higher than that against the casing. In both these cases, the tool joint wear in the abrasive material was excessively severe. This is shown in figure 5, where the OD-wear of all tool joints is plotted as a function of the number of rotations.

NORMALIZING OF THE TEST DATA

For comparison, it is useful to normalize the wear data. For this kind of experiment, with the objective of evaluating different hardfacing materials, and consequently performed under constant test conditions, the data on the tool joint wear or casing wear are expressed in values per kilometer of sliding distance, W. Thfs value, 1,1, is obtained by multiplying the circumference of the joint by the number of revolutions executed and is expressed in units of kilometers. (0.62 miles)

By means of a cross plot with the radial wear in pm divided by the corresponding values of the sliding distance, 11, for easing and tool joints, the quality of the hardfacing can be evaluated. Good hardfacing materials exhibit low wear values for the tool joint as well as for the casing; see figure 6. This diagram includes the results obtained from earlier tests'.

The progress achieved with hardfacing material is quite evident from the graph in figure 6. With earlier hardfacing, endeavors were intended mainly for minimizing tool joint wear, but did not minimize the casing wear. Before testing of the new hardfacing material, it was decided to accept a maximal tool joint wear value, V/W, of 5.6 pm/km (356 pin/mile), and a maximal casing wear, V/11, of 37.3 pm/km (2370 pin/mile) under the specified test conditions. With these borderlines, the grid in figure 7 has four regions, I to IV.

Region I: Low wear for both casing and tool joint

negion II: Low casing wear, but high tool joint wear
Region III: High casing and tool joint wear
Region IV: Low tool joint wear, but high casing wear

Two of the new hardfacing materials tested, 29/6 and R III, passed the test procedure with very good cheracteristics.

the liquid phase during the welding process. The tungsten carbide spheres shown in figure 8 are concentrated at the bottom of the weld close to the structural material of the tool joint. Two spheres have been cut in half during the wear test.

The lowermost curves in figure 5 rorrespond to the tool joints with the best test performance; there are designated as 29/6 and *R III.*

CONCLUSIONS

The tests on eight tool joints with new hardfacing material have demonstrated the possibility of finding a good compromise between protection of the tool joints against wear in abrasive material, and avoidance of severe damage to the casing at the same time.

The new test facility, which allows simultaneous testing of two tool joints, operates very reliably and is flexible with respect to operational conditions, such as rotational speed, linear velocity, and contact forces.

Future tests are planned for investigating the influence of altered test conditions, especially with respect to variations in contact force, and will provide additional information.

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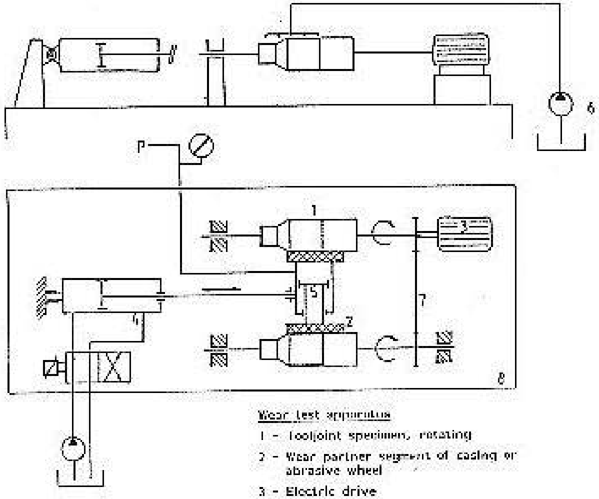
Table 1 Wear protocol 29/6

Cumulative rotations	Wear partner	Measuring positions M 1	M 2	M 3	M 4	Average OD mm	Radial wear µm
		Tooljoint OD mm					
2.400	Casing	186,24	185,77	185,42	185,37	185,70	
57.600	Casing	185,89	185,50	185,39	185,21	185,52	180
115.200	Abrasive	185,44	185,44	185,28	184,96	185,28	420
172.800	Abrasive	185,36	185,34	185,16	184,81	185,17	530
230.400	Abrasive	185,26	185,19	184,94	184,56	184,99	710
288.000	Abrasive	185,07	185,02	184,60	183,81	184,64	1060
345.600	Abrasive	184,84	184,80	184,65	183,75	184,51	1190
403.200	Abrasive	184,79	184,65	184,54	183,71	184,42	1280
460.800	Abrasive	184,70	184,54	184,45	183,56	184,31	1390
518.400	Casing	184,44	184,40	184,36	183,36	184,14	1560

Table 2 Test results

PK	Casing			Tooljoint		
	W (km)	V (µm)	V/W	W (km)	V (µm)	V/W
29/8	66.77	530	7.94	267.09	3190	11.94
29/1	133.55	1000	7.49	306.04	4270	13.95
29/6	66.77	1080	16.17	300.48	1560	5.19
29/7	100.16	1100	10.98	300.40	2680	8.92
32	133.55	2590	19.39	306.04	5700	18.62
29/9	66.77	1560	23.36	300.48	4110	13.68
29/10	66.77	1830	27.41	267.09	3770	14.12
R 111	100.16	2380	23.76	300.40	1210	4.03

PK	Tool joint code number
W	total distance slid km
V	radial wear µm
V/W	specific wear µm/km



Wear test apparatus

1 - Tooljoint specimen, rotating
2 - Wear partner segment of casing or abrasive wheel
3 - Electric drive
4 - Hydraulic cylinder for axial movement
5 - Hydraulic load cell for contact force between wear partners
6 - Mud pump
7 - Transmission chain
8 - Frame

Fig.1 Wear test apparatus

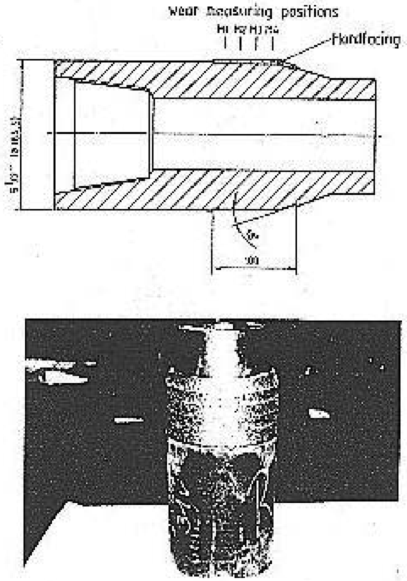


Fig.2 Tooljoint

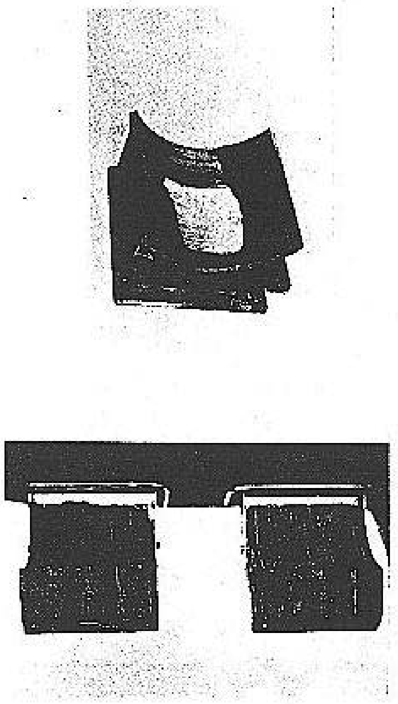


Fig.3 Wear partners, casing or abrasive wheel

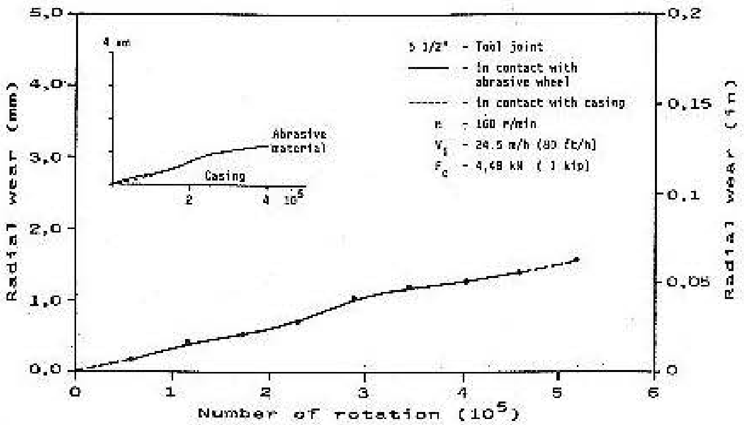


Fig.4 Wear curve

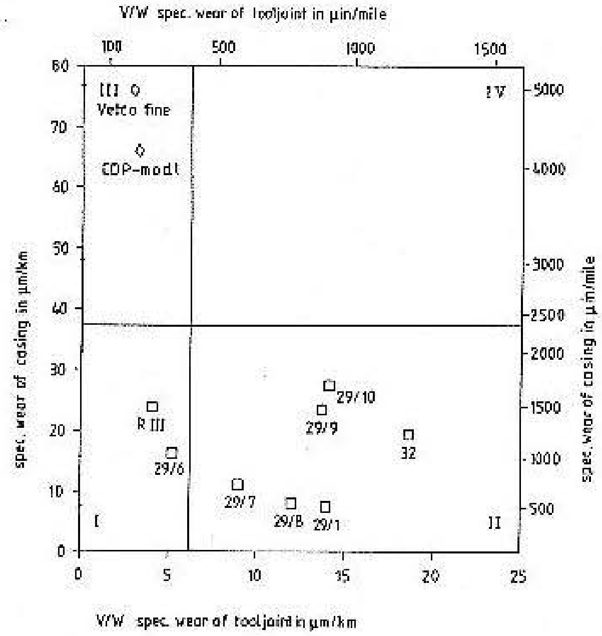


Fig. 6 Spec. wear diagram, casing vs tooljoint

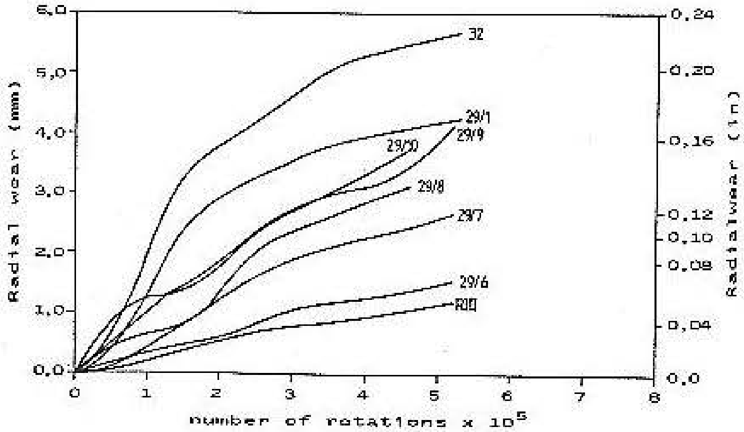


Fig.5 Wear curves

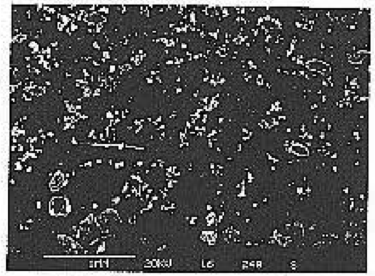


Fig.7 Hardfacing material 29/6, Microstructure

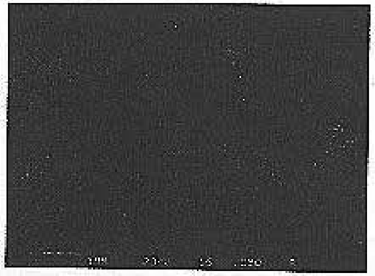


Fig.8 Hardfacing material RIII, Microstructure