LABORATORY TESTS ON THE DRILLABILITY OF ROCKS AND EVALUATION OF TRI-CONE BITS PERFORMANCE AT ELEVATED TEMPERATURE

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ABSTRACT

The air drilling test facility was manufactured to investigate the drillability of rocks and the life-time of full-scale rock bits at elevated temperature; Bits used for these tests are 9 tungsten carbide inserts tri-cone bits of 8½-in. diameter.

The results obtained from the drilling tests for granite and andesite up to 350°C showed that the penetration rate for granite increased with a rise of rock temperature, but there was no significant change of penetration rate for andesite. Life-time tests of 7 bits with hot cast-iron blocks conducted to evaluate the bit performance at elevated temperature. Through the tests. bits were encountered several troubles such as loosing or breakage of tungsten carbide inserts and damage of rotation mechanism of the roller cutter caused by breakage of the bearing, deterioration of the seal and entering of cast-iron cuttings into the bearing. Practical experience and knowledge given from the tests will be useful to point out disadvantageous portions of conventional tri-cone bits under high temperature and for further improvements of the bit.

INTRODUCTION

Six geothermal power stations operated with steam of around 200°C in temperature have been constructed in Japan. Geothermal reservoirs which supply energy to these power stations are considered to exist at the depth of relatively shallow 1000-1500 m, and the generating power per one power station is less than about 50 MW. Several prospecting wells drilled recently, aiming at the development of deeper reservoirs to obtain greater output rated to at least 100 MW, have reached at the depth of about 3000 m and the formation temperature of about 300°C. Moreover, the development of hot dry rock geothermal energy which needs drilling equipments capable of withstanding more severe conditions than the development of natural geothermal reservoirs is about to be carried out (Cremer *et al.*, 1980). Drilling conditions such as the well depth, bottom-hole temperature, pressure and rock hardness, therefore, will become more severe in near future. Appearance of new bits which have sufficient durability and drillability at high temperature probably cuts down the drilling cost of such wells above mentioned, also may promote utilization of geothermal resources which have never been developed until now. It is important to have a test machine able to evaluate the performance of new or conventional rock bits at elevated temperature in advance of practical use.

The air drilling test facility and the mud drilling test facility called "wellbore simulator" (Black, 1977; Hendrickson *et al.*, 1978) were manufactured to investigate the drillability and the life-time of full-scale rotary bits at elevated temperature (Fig. 1 and Fig. 2). In this paper, the drillability of granite and andesite and the life-time of 7 tungsten carbide inserts tri-cone bits of 8½-in. diameter under high temperature will be reported, which are only obtained from the tests with the air drilling test facility.

EXPERIMENTAL PROCEDURE

The air drilling test facility as can be seen in Fig. 1 consists mainly of the drill rig, air compressor, electric furnace, gas furnace, heat exchanger and dust collector. Main specifications of the facility are as follows.

rotational speed	0-400 rpm
maximum thrust	40 ton
maximum torque	400 kg-m

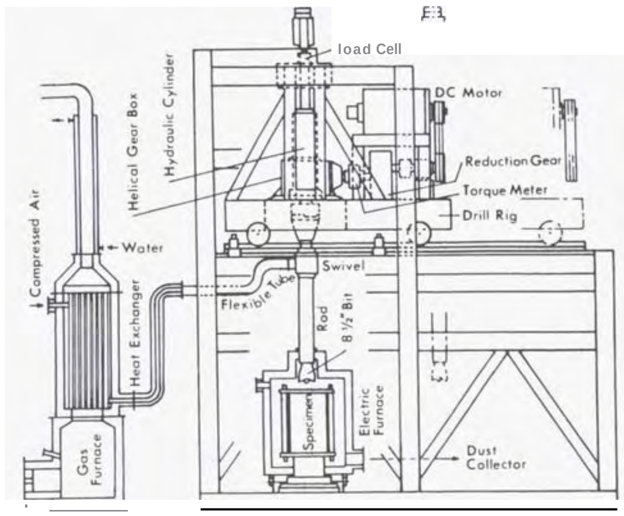


Fig. 1 Outline of the air drilling test facility; maximum temperature = 400°C, specimen size = 50 × 50 × 80 cm.

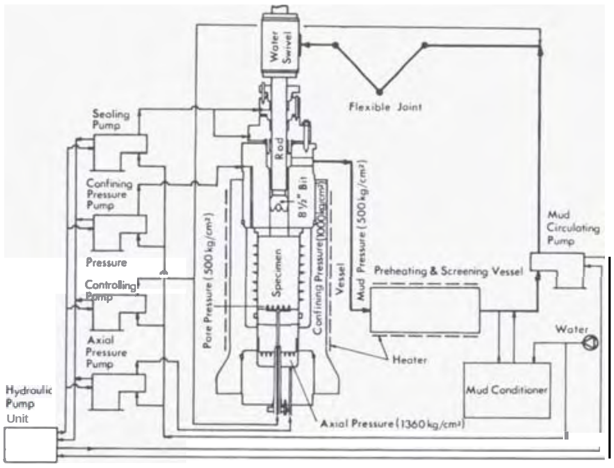


Fig. 2 Schematic diagram of the wellbore simulator; maximum temperature = 150°C, specimen size = 50 ϕ × 90 cm, closed circulation system.

maximum temperature of specimen, compressed air and atmosphere	400°C
maximum air flow rate	6 Nm^3/min
specimen size	50 × 50 × 80 cm
bit diameter	8½-in.

The specimen block is fixed in the electric furnace and heated up to a desired temperature at a uniform rising rate, being monitored with a thermocouple in the center of the specimen. During the test heated compressed air of equivalent temperature to the specimen is blown into drilled hole to prevent the temperature drop of the specimen and to remove cuttings. Specimens used for drillability tests are granite and andesite, for life-time tests of bits the cast-iron is selected. Through the test, bit load, torque, penetration rate and temperature of the specimen and air were measured and recorded. After the test temperature of the roller cutter was measured immediately, then bits were decomposed to observe a state of bit inside precisely.

9 tungsten carbide inserts tri-cone bits of 8½-in. diameter used for tests are shown in Fig. 3, and the special features of each bit are given in Table 1.

THE DRILLABILITY OF HOT ROCKS

Drilling tests for granite and andesite were conducted at room temperature, 150°C, 250°C and 350°C. Through the test air pressure, flow rate and rotational speed of the bit were kept constant at 5 kg/cm^2, 5.4 Nm^3/min and 50 rpm respectively. The value of flow rate, 5.4 Nm^3/min, is enough to remove cuttings because cuttings on a bottom-hole could not be found under the maximum bit load.

Fig. 4-(1) shows relationship between bit load and penetration rate of granite as a function of rock temperature. Penetration rate at a certain load increases as the temperature rises. For example, the penetration rate obtained at the bit load of 15 ton increases about 20% when rock temperature rises from room temperature to 350°C. On the other hand for andesite there is no significant change of penetration rate with a rise of rock temperature (Fig. 4-(2)). The relationship of penetration rate versus torque for granite and andesite as a function of rock temperature is plotted in Fig. 5-(1) and Fig. 5-(2) respectively. Torque necessary to obtain a certain penetration rate decreases for granite, while for andesite clear change of torque can not be observed as the temperature rises. For example, torque obtained at the penetration rate of 15 cm/min for granite decreases more than 20% when rock temperature rises from room temperature to 350°C. From the data of drillability tests it is clear that granite becomes easy to be drilled with a rise of rock temperature. These results agree well with that of penetration tests conducted with single button tip bits (Misawa and Kuriyagawa, 1978).

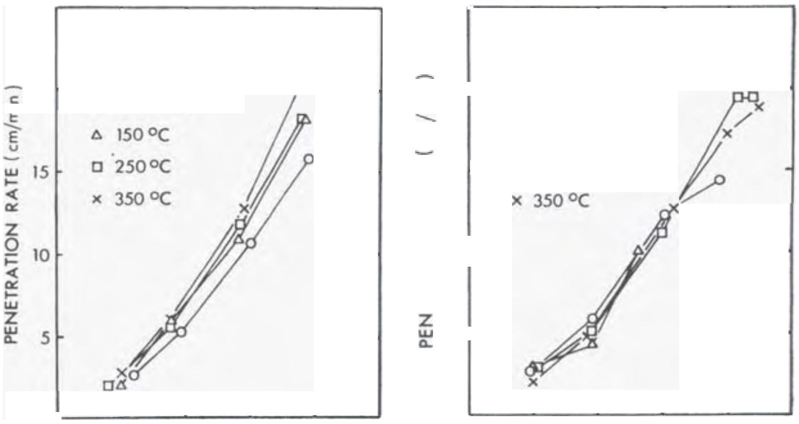
It is considered that mechanical properties of rock such as compressive strength, tensile strength, and Young's modulus etc. influence the penetration rate for drilling. For example, the penetration rate generally decreases when the compressive strength of rock increases (Clark, 1979). The uniaxial compressive strength of granite and andesite was measured at the same temperatures as the drilling test to compare with the drillability of each

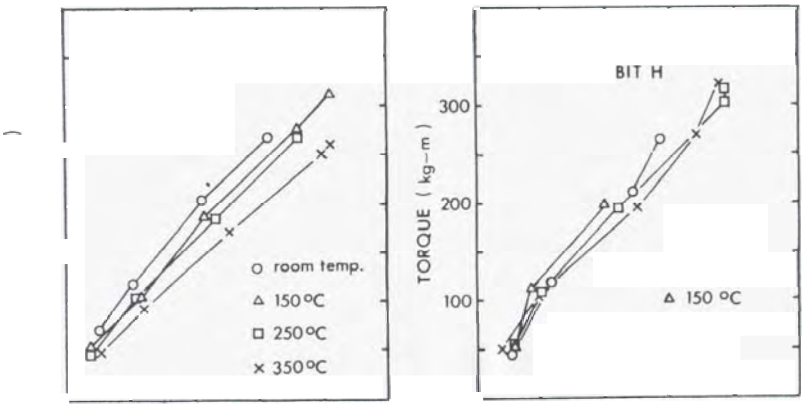
Fig. 3 Appearances of 9 bits for tests.

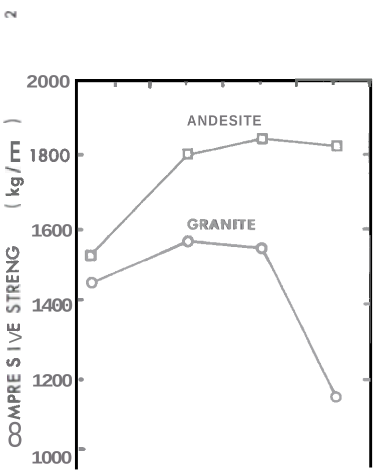
Table 1 The special features of 9 bits

symbol	type	features
A	mud bit	roller bearing, metal seal, PMS cutter*
B	mud bit	friction bearing, elastmer seal
C	air bit	roller bearing, non-seal
D	mud bit	roller bearing, metal seal
E	mud bit	roller bearing, metal seal
F	air bit	roller bearing, non-seal, PMS cutter*
G	air bit	friction bearing, non-seal, PMS cutter*
H	air bit	roller bearing, non-seal
I	mud bit	friction bearing, elastmer seal

PMS cutter* : powder metallurgically sintered cutter







strenath of about 14 kg/mm^2) because it was considered that FC-25 was too hard to be used as for life-time tests of the bit. Temperatures of cast-iron blocks were changed in the range of 150-300°C in order to investigate the temperature influence on the bit life-time. The bit load was raised in steps to allow smooth bit rotation and finally the life-time test was conducted at the bit load of 15 ton.

The relationships between running time and torque of 7 bits are shown in Fig. 7. In the case bits work normally, torque necessary for 50 rpm bit rotation is about 40 kg-m at the thrust of 5 ton, 70-80 kg-m at 10 ton and 100-110 kg-m at 15 ton. With the passage of running time, few bits show a moderate increase of torque but most of the decreases generally with the temperature rises, for example, bit E has the life-time less than one half of bit D. the same type as bit E, when the temperature increases from 150°C to 300°C. The temperature of all roller cutters just after the test showed more than 200°C and the maximum temperature of more than 400°C was recorded in a few bits. Even though bits were exposed to such high temperature, deformation of the bearing was not observed except bit F.

Troubles related to rotation mechanism of bit A, C, D and E are due to entering of cast-iron cuttings into the bearing (Fig. 8). It is considered that such entering is came from an indequate sealing performance of the metal seal except bit C. Sealing performance of the metal seal available today is not so good as that of the elastmer seal, but application of the metal seal to the bit is one of the best way to protect bearing parts when bits are used in the circumstances of high temperature and pressure. Therefore, design and trial manufacturing of "improved metal seal" which has a sufficient sealing performance is going on, and the test with the bit in.which the improved metal seal is installed is scheduled in this year with our test facility. As to the elastmer seal, thermal deterioration were observed after the long time exposure to high temperature more than 200°C (Fig. 9). The lubricant was dispersed by breakage of the elastmer seal, so that overheating of the bearing stopped rotation of the roller cutter and created excessive torque. Rotation of inserts as can be seen in Fig. 10 occurs typically in the roller cutter which rotation mechanism is damaged. One of the causes of inserts rotation may be a decrease of holding force of insert resulting from differencies of coefficient of 1inear expansion between the materials of insert and that of the roller cutter shell, but it is considered that the main cause is a large moment forced on inserts due to the stopping of the cutter rotation.

The roller cutter of bit A, F and G were made from metal powder by metallurgically sintering, at first tungsten carbide inserts were setted in the powder of metal which becomes the cutter shell then sintered, so that it has an advantage that the falling or loosing of inserts does not occure. But several inserts of the cutter which rotation mechanism was damaged were broken during tests. It is not clear that the breakage of inserts originates in whether a large moment forced on the "fixed" inserts or problems of something such as residual thermal stress when they were sintered with the metal powder. More tests must be carried out to judge whether the sintered cutter can be used practically or not. Bit G, which has the friction bearing cooled and lubricated bv air. shows extremely high torque arises from friction between the cutter and bearing flanges which support the bit load. Therefore, the performance of the friction bearing itself could not be evaluated by the test. Redesign and improvement of flanges are being conducted. The bearing of bit F were deformed by excessive overheating caused by inadequate welding of hard metal on the bearing surface.

From the results of the 7 life-time tests it is considered that the bearing, roller cutter and leg have fairly high heat resistance and that various troubles of most bits are caused essentially

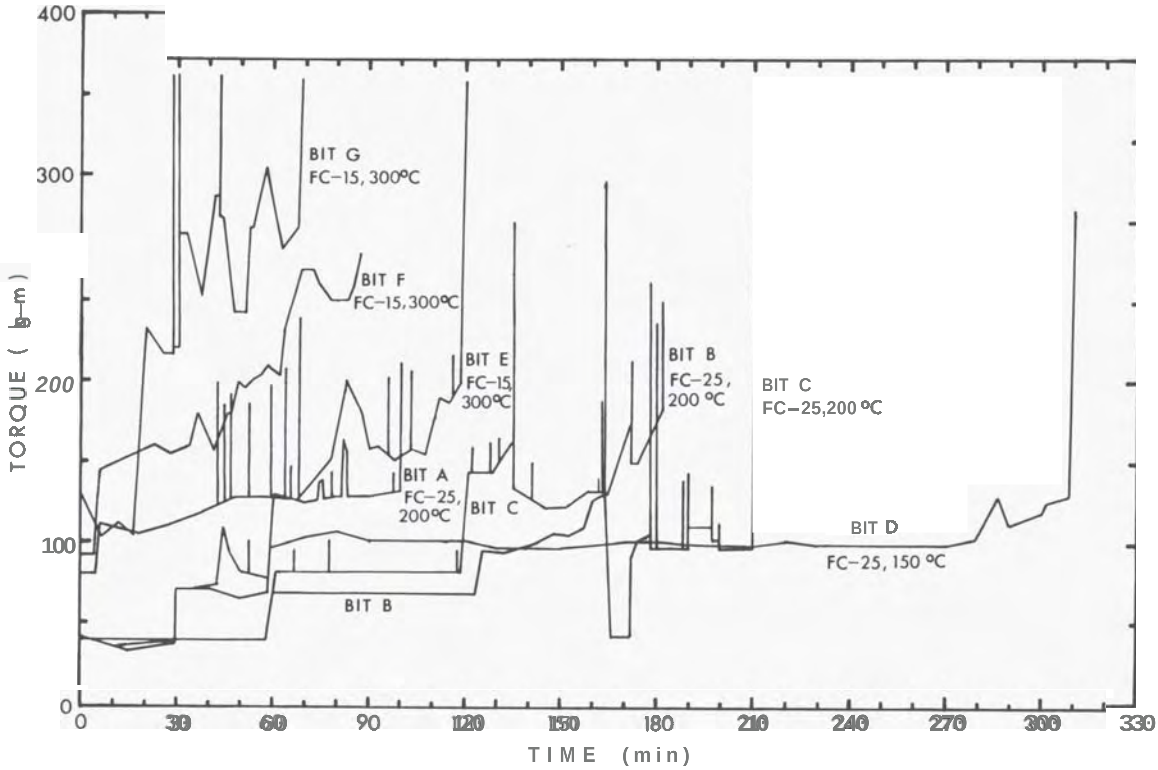


Fig. 7 Running time vs. torque at elevated temperature.

Fig. 8 Cast-iron cuttings entered into the roller bearing.

Fig. 9 The elastmer seal broken by thermal deterioration.

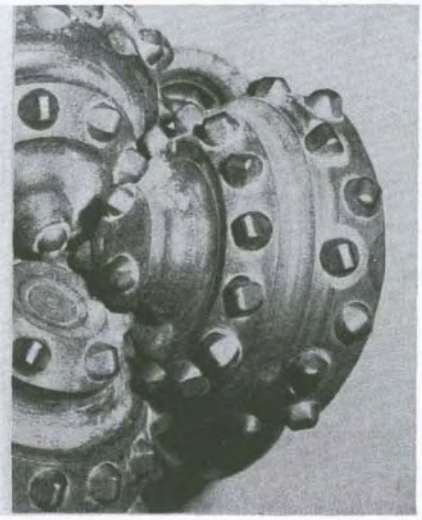


Fig. 10 Inserts rotated in the roller cutter.

by damages of the seal. Development or improvement of the seal having high heat resistance *is* very important to increase the life-time of bit and it is desired to test the bit in which the "improved metal seal" is installed as early as possible.

One of our final goals is to evaluate the bit performance, drilling time or drilling footage, with our test facilities in advance of practical use for geothermal well drilling. The second is to provide the data for further improvements of the rock bit.

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