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# Self-Welding Behavior of Various Materials in a Sodium Environment(V) Frictional Behavior of the Candidate Materials for Duct Pad in the Various Environment.



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POWER REACTOR AND NUCLEAR FUEL DEVELOPMENT CORPORATION

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# Self-Welding Behavior of Various Materials in a Sodium Environment (V)

## Frictional Behavior of the Candidate Materials for Duct Paid in the Various Environment

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### Abstract

We have been conducting a series of self-welding and friction tests for the material selection of the contacting and sliding parts used in a fast breeder reactor.

In the present study, we tested some candidate materials for duct pads of the fuel-assembly in high temperature sodium and argon, and made the evaluation of these materials.

The following results were obtained:

(1) Stellite No. 6 showed the stable frictional behavior in 280 °C sodium, but increased the frictional coefficient and flushing effect in 540 °C sodium.

(2) Colmonoy No. 6 showed the stable frictional coefficient of 0.3 ~ 0.4 under a heavy load (500 kg) or in high temperature sodium.

(3) Chrome-carbide materials showed the different frictional behavior according to the methods for finishing of the test surface. Frictional coefficient of the grinder-finished chrome-carbide exceeded 1.0, and indicated a greater flushing effect in 540 °C sodium.

(4) Hard chrome plating showed an unstable frictional behavior, the frictional coefficient being 0.8 even in 280 °C sodium.

(5) Inconel 718 showed a high frictional coefficient of 0.6 ~ 0.8, but indicated a stable frictional behavior.

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## 1. Preface

In selecting the padding materials for FBR in-pile fuel assemblies, careful evaluation is necessary to be made on the two points that no self-weld takes place at the time when any clamping has occured in high temperature sodium and that friction resistance between the fuel assembly padding sections at the time of fuel exchange operation should be as small as possible.

In the present experiment, a series of friction tests were performed on the six kinds of candidate materials which had been selected as the results of the preceding tests. Also environments and at room temperatures. The results of these tests are reported by comparing with each other's data. The equipment employed for the present friction test was the newly made self-welding equipment (SW-2).

## 2. Procedures of Experiment

### 2-1 Test Equipment

The test equipment employed for the experiment was the PNC developed self-welding tester which was installed into the testing pot (SW-2) of the self-welding and friction test loop. And the experiment was performed under various test conditions. Fig. 1 shows the general conception of the test equipment, while Fig. 2 shows the flowsheet of the test loop. Photo-1 represents the external appearances of test specimens and test equipment after test in high temperature sodium and argon gas. The same test equipment was employed for both the in-sodium test and the in-high temperature inert gas test. For the in-sodium test, purified sodium was constantly recycled into the testing pot from the mother loop, while the test in the inert gas was performed by constantly feeding pure argon gas into the sealed type 316 SS tube to maintain an argon atmosphere at all times. In this case, a vacuum pump was used to replace completely with argon gas. For the heating at this time, an electric furnace of Kanthal wire was employed to heat up the type 316 SS tube directly. Photo-1 also represents the external appearances of the tested specimens. The temperatures of the test pieces exposed to high temperature argon environment were measured directly by use of a thermocouple buried in the depth of about 2mm form the frictional contact surface of the specimens. The in-sodium temperature measurement of test pieces was performed by measuring the temperatures of the testing pot.

The position of the in-sodium test frictional contact face was at the depth of about 100mm from the sodium liquid level. The major specifications of the self-welding test equipment which was employed for the present experiment are given as follows:

| | |
|---|---|
| 1. Pressure load ( max) | 4,000Kg |
| 2. Tensile load ( max) | 2,000Kg |
| 3. Torsion torque | ±20Kg·m |
| 4. Rotation angle | 120 ° |
| 5. Mode of motion | Reversed rotating motion |
| 6. Vertical stroke | 0 ~ 10 mm |

2-2 Test Conditions

The test conditions for the present experiment are as shown by Table 1.

Table 1. Test Conditions

| Environment | Test Conditions | |
|---|---|---|
| Sodium | Temperature (°C) | 280, 540 |
| | Cold Trap Temp. (°C) | 200 |
| | Flow Rate (ℓ/min) | 4 |
| | Load ( Kg) | 0 ~ 1,000 |
| | Flushing Time (hrs) | 16 |
| Argon | Temperature (°C) | 280, 540 |
| | Flow Rate ( ℓ /min) | 0.5 |
| | Purity (%) | 99.999 |
| | Load ( Kg) | 0 ~ 1,000 |
| | Friction Velocity (mm/min) | 147 |

In respect of temperature, load and frictional sliding velocity, the conditions were set identical for both the in-sodium and the in-argon tests for the convenience of data comparison. As the present experiment was aimed for the selection of materials for the FBR fuel assembly padding section, the conditions of test were simulated as much as possible to the actual operating conditions of FBR fuel assemblies. Here, the temperature 540 °C is the temperature in the vicinity of the FBR fuel assembly padding section under the actual reactor operation, and 280 °C is the in-pile temperature at the time of fuel exchange. It is also estimated that the load of 200 ~ 500 Kg produced in-between the pads for fuel assemblies when a clamping method is employed. Therefore, the tests were conducted under the load close to such load weight. As for the frictional sliding velocity, since no design values for fuel exchange velocity were yet known, the tests were conducted at such velocities at which the self-welding tester showed less fluctuations.

(Note: The exchange velocity of MONJU adjusted design value is 300mm/min. max.)

## 2-3 Configuration and Chemical Composition of Test Specimens

The dimensions of the test specimens are as shown in Fig. 3, and a jig was set up to prevent any off-set contact of specimens. Table 2 represents the chemical compositions of the test specimens which were prepared from those prospective candidates for the padding materials screened so far by our previous test. Only the same material combinations were subjected to the present friction and wear tests. The test specimen preparation methods are shown in Table 3.

Table 2. Chemical Composition of Test Specimens

| Material | C | Si | Ni | Co | Cr | Fe | Mn | B | Mo | W | V | P | Cb + Ta | Ti | Al |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Stellite No. 6 | 1.04 | 1.17 | | Bal | 28.65 | 0.27 | | | | 4.20 | | | | | |
| Colmonoy No. 6 | 0.75 | 4.25 | 73.75 | | 13.5 | 4.75 | | 3.00 | | | | | | | |
| Inconel 718 | 0.07 | 0.15 | 53.81 | 0.07 | 18.45 | | 0.16 | | 3.12 | | | 0.004 | 5.12 | 0.85 | 0.71 |
| Hard Cr Plating | | | | | 100 | | | | | | | | | | |
| LC−1C[※1] (B・F) | 85% $Cr_3C_2$ + 15% Ni・Cr (Brush Finishing) | | | | | | | | | | | | | | |
| LC−1C[※2] (G・F) | 85% $Cr_3C_2$ + 15% Ni・Cr (Grinder Finishing) | | | | | | | | | | | | | | |

LC-1C[*1] (B.F.): Applied with a brush finish-up after D-Gun coating and have surface roughness of 10 μm.

LC-1C[*2] (B.F.): Surface has a grinder polish with surface smoothness below 1 μm.

Table 3. Manufacturing Methods of Test Specimens

| Materials | Manufacturing Methods |
|---|---|
| Stellite No. 6<br>Colmonoy No. 6 | Oxy-Acetylene Gas Weld |
| LC-1C | Detonation Gun Coating on Type 316 SS |
| Hard Chrome Plating | Electroplating on Type 316 SS |

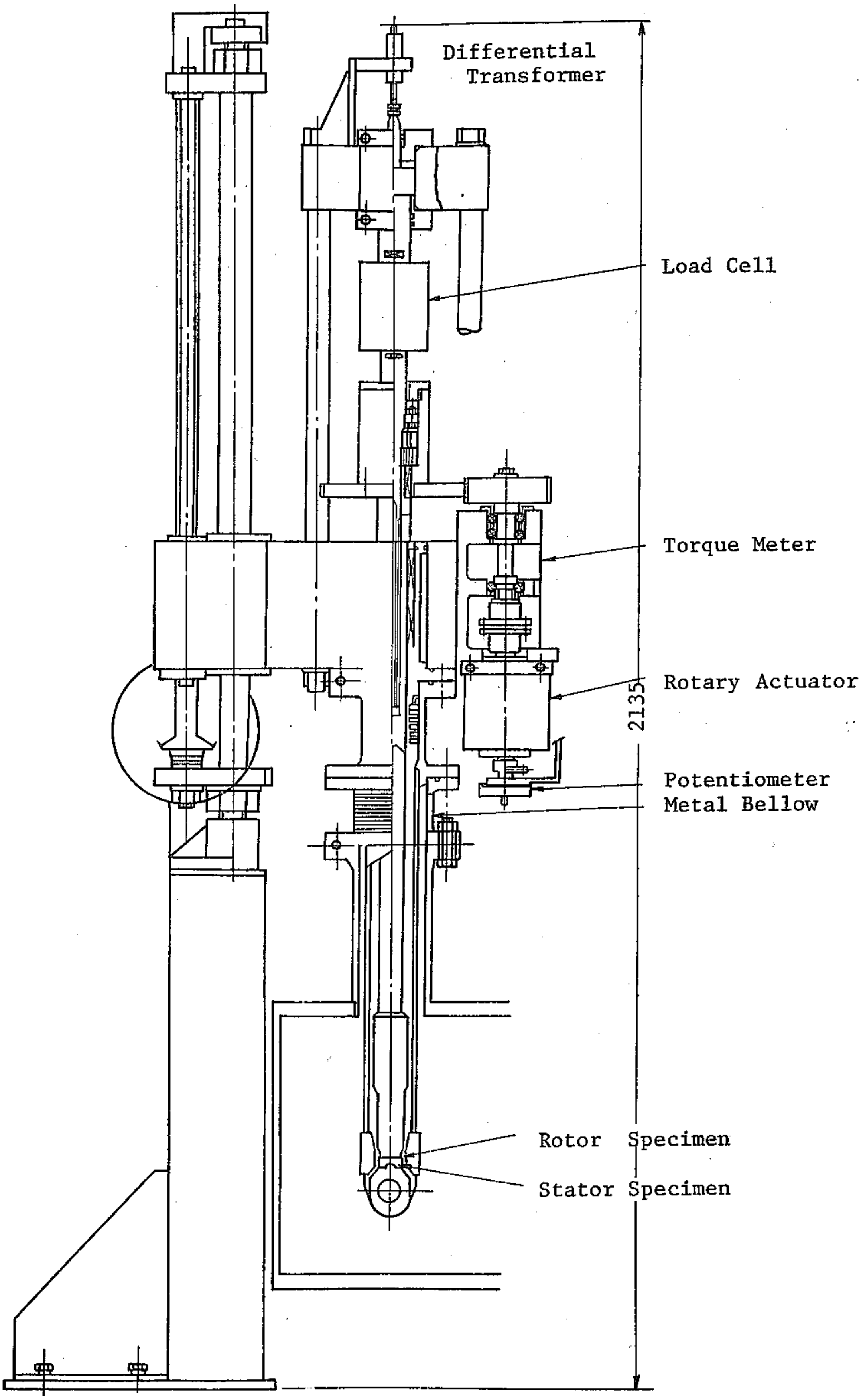
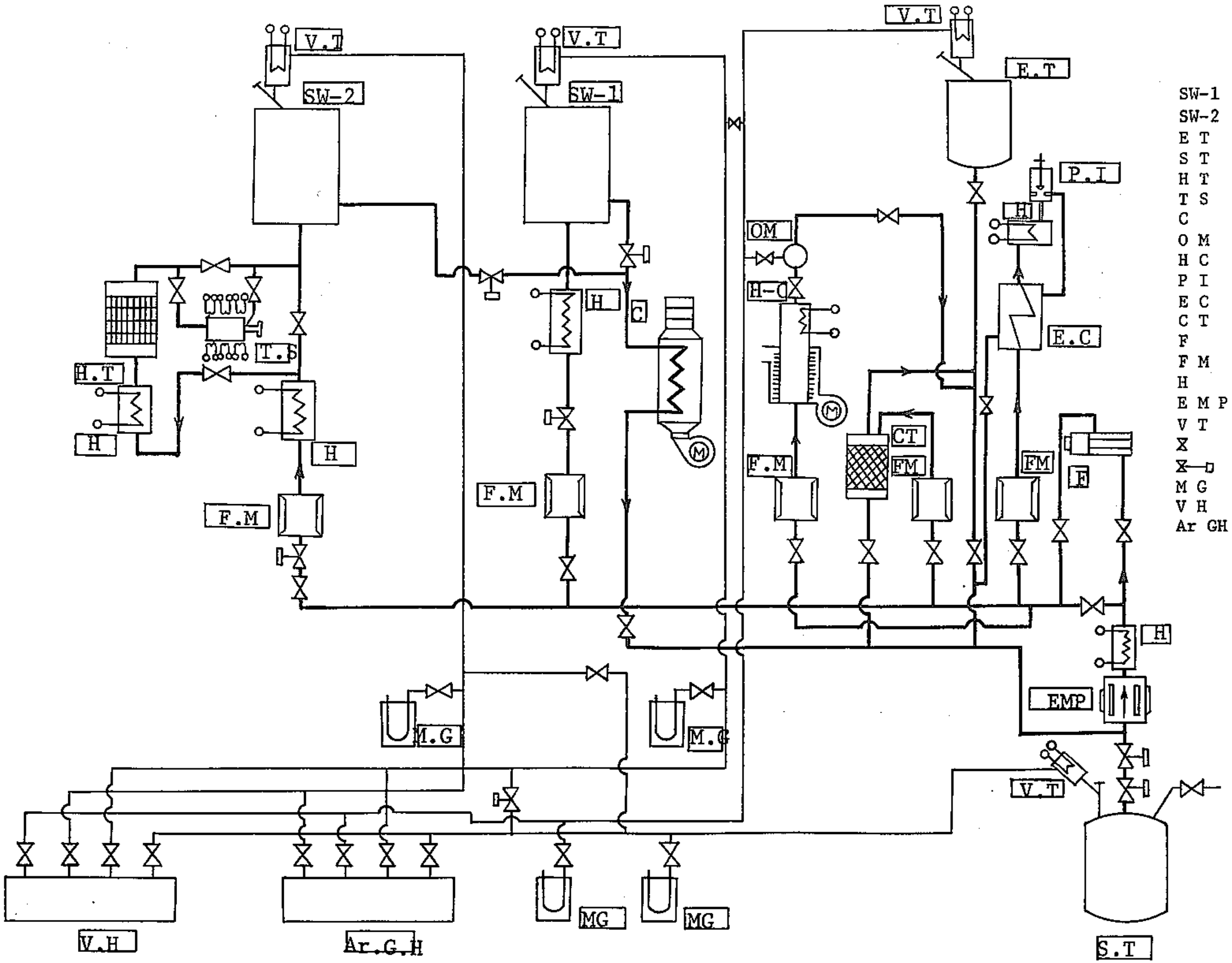



Fig. 1 Self-Welding Test Equipment




| | |
|---|---|
| SW-1 | Wearing Test Pot |
| SW-2 | Self-Welding Test Pot |
| E T | Expansion Tank |
| S T | Storage Tank |
| H T | Hot Trap |
| T S | Corrosion Test Section |
| C | Cooler |
| O M | Oxgen Meter |
| H C | Heater and Cooler |
| P I | Plugging Indicator |
| E C | Economizer |
| C T | Cold Trap |
| F | Filter |
| F M | Electro Magnetic Flow Meter |
| H | Heater |
| E M P | Electro Magnetic Pump |
| V T | Vapor Trap |
| X | Manual Valve |
| X—□ | Automatic Valve |
| M G | Manometer Gauge |
| V H | Vacuum Header |
| Ar GH | Argon Gas Header |

Fig. 2 Flow Sheet of Self-Welding and Wearing Test Loop

Table 4 represents the final test load on various material combinations in various environments. The values were decided by the maximum values of various frictional torques. The metallographic analysis of the frictional contact surfaces of materials after test must take these values into consideration.

Table 4. Final Load on Friction Test of Various Materials

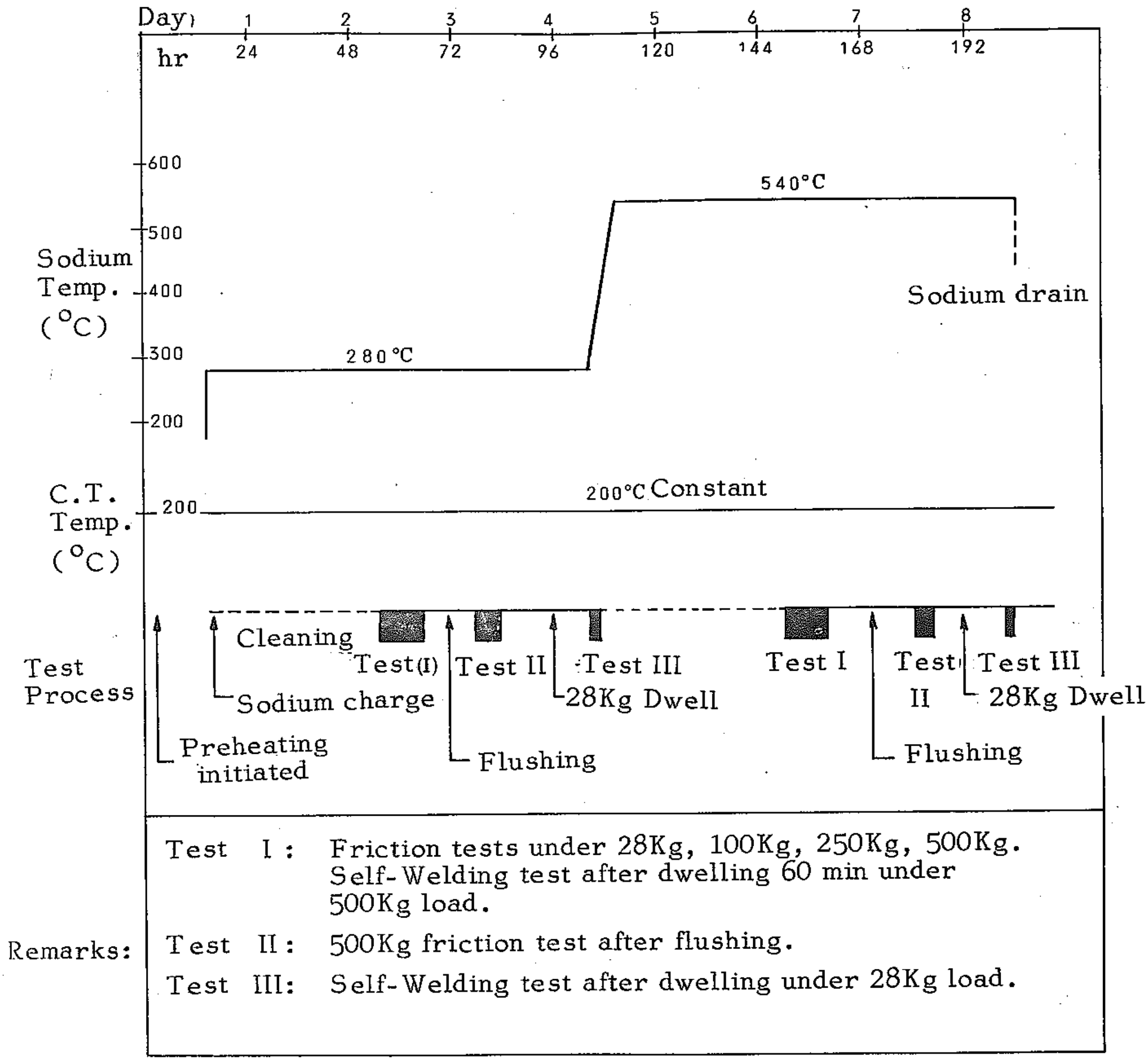
| Material Combination | Environment | Final Load |
|---|---|---|
| Colmonoy №6 vs. Colmonoy №6 | in Air | 1,000 |
| 〃 〃 | in Argon | 1,000 |
| 〃 〃 | in Sodium | 500 |
| Stellite №6 vs. Stellite №6 | in Air | 1,000 |
| 〃 〃 | in Argon | 1,000 |
| 〃 〃 | in Sodium | 500 |
| LC1C(B・F) vs. LC1C(B・F) | in Air | 1,000 |
| 〃 〃 | in Argon | 1,000 |
| 〃 〃 | in Sodium | 500 |
| LC1C(G・F) vs. LC1C(G・F) | in Air | 500 |
| 〃 〃 | in Argon | 500 |
| 〃 〃 | in Sodium | 500 |
| Hard Cr Plating vs. Hard Cr Plating | in Air | 500 |
| 〃 〃 | in Argon | 500 |
| 〃 〃 | in Sodium | 750 |
| Inconel 718 vs. Inconel 718 | in Air | 500 |
| 〃 〃 | in Argon | 500 |
| 〃 〃 | in Sodium | 750 |

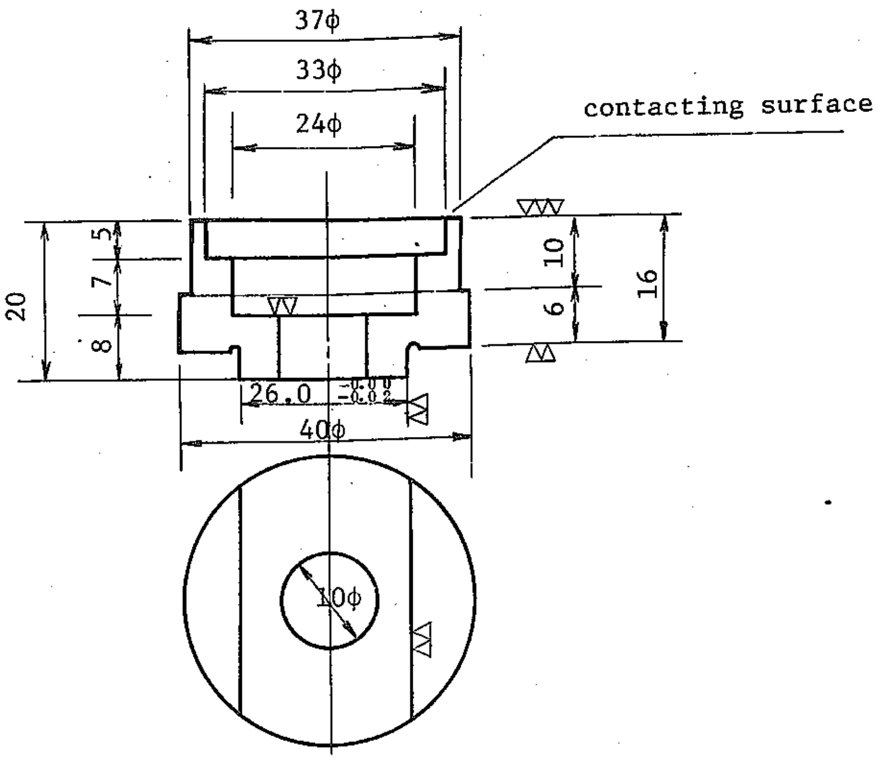
In the present experiment, the frictional cycle was repeated three times under each test condition to observe frictional behavior of materials in various combinations.

The operation schedule of in-sodium tests is shown as follows:

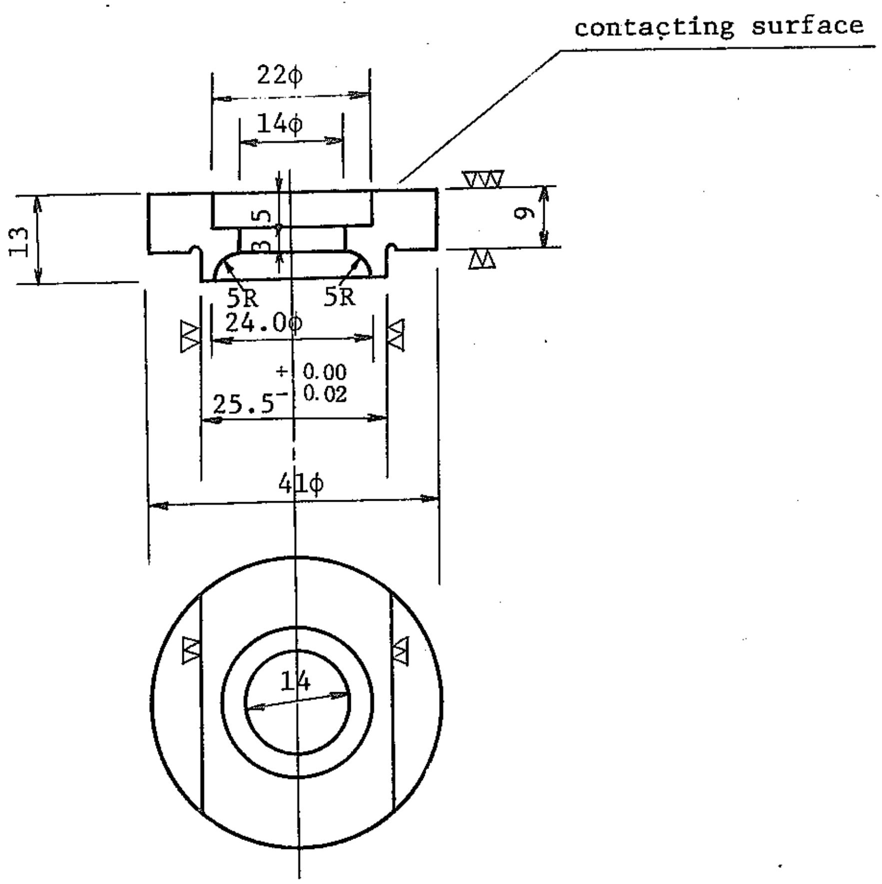
又，今回の試験では，各々の試験条件で摩擦サイクルを3回づつ繰返し，これから摩擦挙動を観察した。

なお，ナトリウム中試験時における運転スケジュールを下記に示す。






Rotor Specimen




Stator Specimen

Fig. 3 Dimensions of Specimen

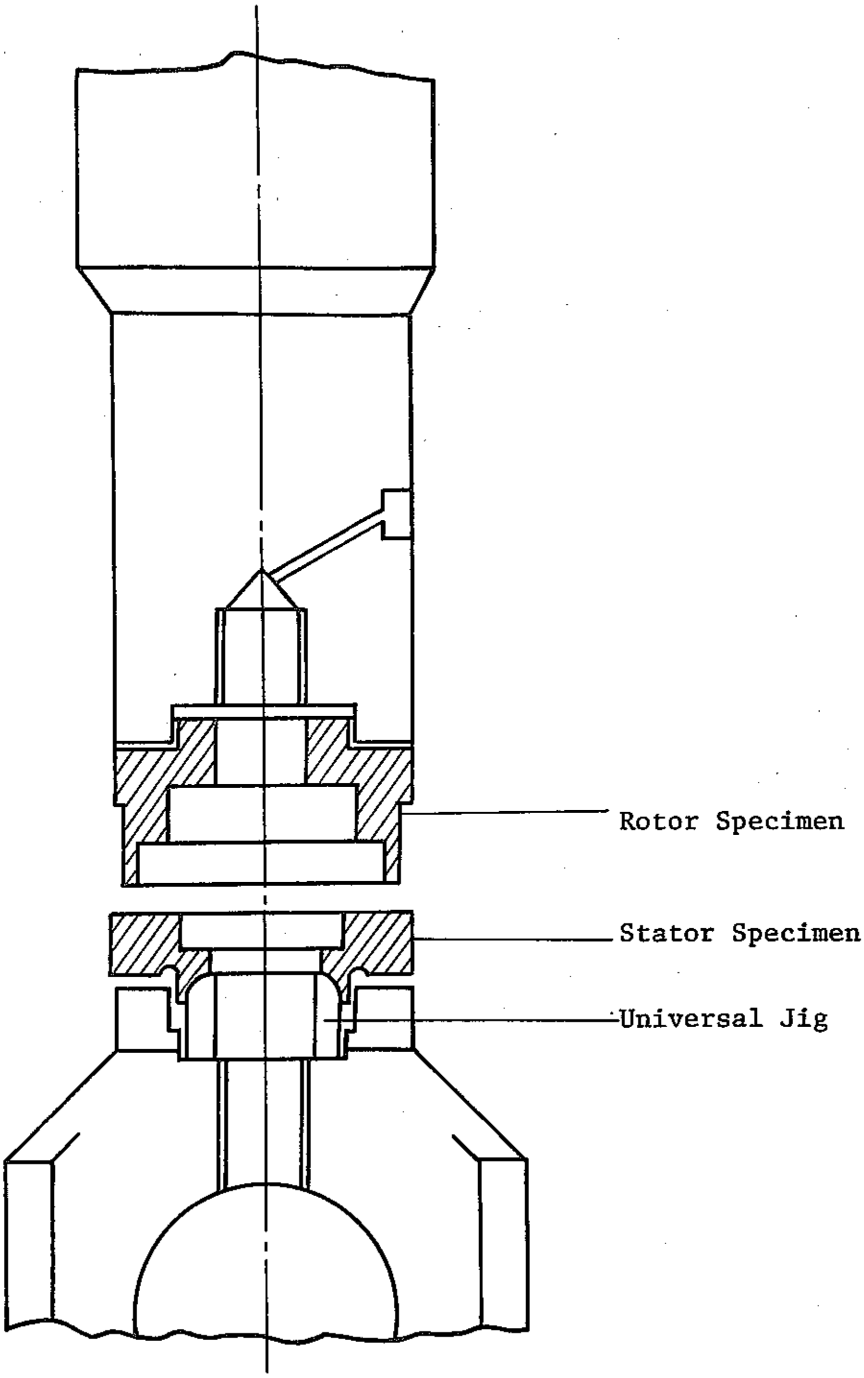



Fig. 4 Assembly for Self-welding Test

2-4 After-Test Analysis

During the friction test, the frictional sliding torque value against the rotational angle and the variation of load (real measured load*) were recorded by an X-Y recorder, from which the frictional coefficient was calculated from the following expression:

$$\mu = \frac{T - T'}{R \cdot L}$$

Here, $\mu$ : Frictional coefficient.

R : Mean radius (m) of test specimens.

L : Measured load (Kg).

T : Measured torque (Kg·m).

T' : Torque (Kg·m) under no load.

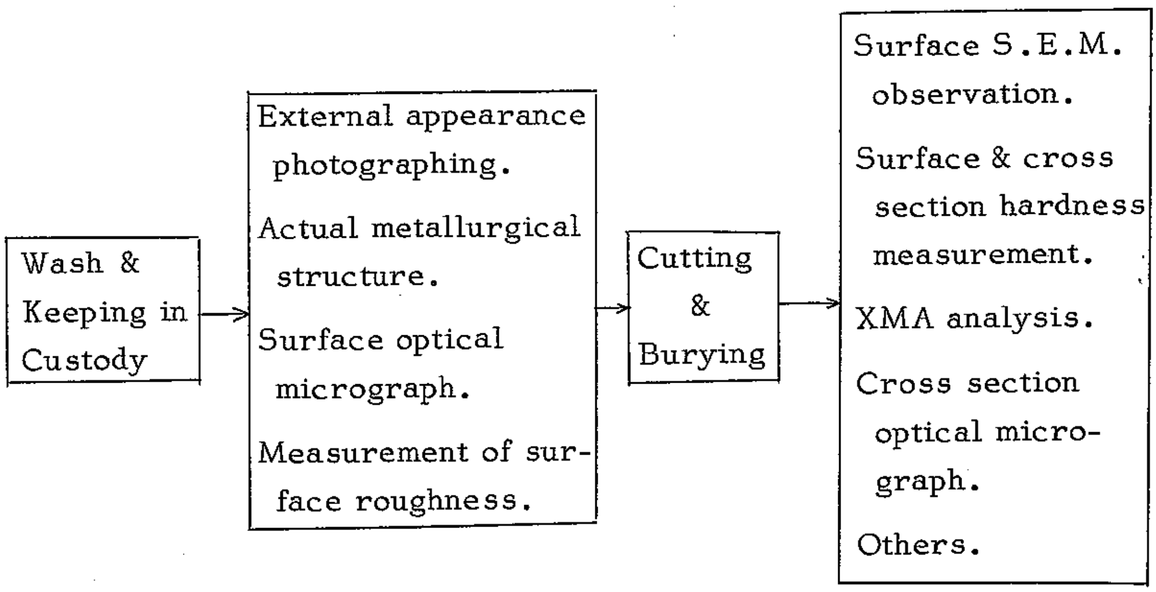
(The previous report gave the value of T' as 0.02Kg·m(3))

For the purpose of evaluating self-weldability, measurement of initial torque was conducted after holding the specimens under pressure for a given time. Also were measured and recorded the displacement rate of specimens and variation of load for the given holding time.

*(This value is called the true measured load, and the load which is set at the initiation of the friction test is classified as the nominal load. When the present frictional tester applies a vertical pressure upon the test specimens by means of a hydraulic press, the initially set load changes. With the combination of such materials of which frictional behavior is stable, this type of load fluctuation is below 1%, while in the case of type 316 SS vs. type 316 SS combination, of which frictional behavior is most unstable, its load fluctuation rate is close to 20%. This load fluctuation is called the actual measured load, and

is recorded at all times. The load weight for the low friction test was applied by the dead load in which case, there was no load fluctuation.)

The test specimens after completion of friction and self-welding tests were extracted from the sodium pot and were held in custody after alcohol washing. These test specimens were subjected to after-test review and evaluation in respect of their friction and self-welding characteristics in compliance with the following analytical items:




Please refer to the previous report(4) for the details of the analytical instruments employed for this analysis.

## 3. Results of Experiment and Consideration

### 3-1 Frictional Characteristic of Stellite No. 6 Same Material

The friction test was performed by repeating three frictional cycles under given conditions and the frictional torques for various frictional sliding angles were recorded and compared with each other. Fig. 5 gives the data of the friction test on the same material combination of Stellite No. 6 at both room and high temperatures.

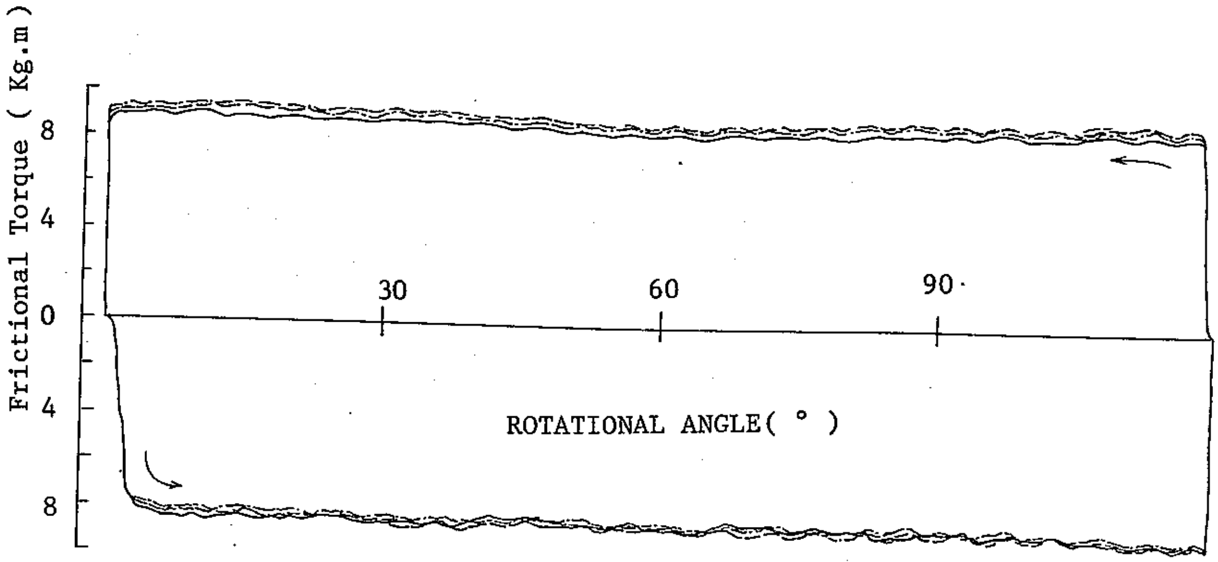
The arrow marked indication in the graphs shows the frictional sliding direction. The one which was tested at room temperatures was applied with a load of 1,000Kg, and showed hardly any change in frictional torque values and indicated stable behavior in the friction of same materials. Also, either the first cycle or the 3rd cycle, the frictional behavior showed the similar pattern. And it was observed that when there was no change on the frictional surface of materials, there was neither any variation in frictional coefficient. Thus, at room temperature, the test showed quite stable frictional behavior.

In a high temperature argon atmosphere at 540 °C, a partial unstable frictional behavior was observed in some regions, and higher frictional coefficient than in the case of the room temperature test were indicated. Fig. 6 shows the results of in-sodium test of stellite materials. An evident lubricating effect is seen in 280 °C sodium, and lower frictional torque values are indicated than in the case of room temperature and high temperature argon atmosphere. However, frictional behavior stability is poor comparing with that of the room temperature test, in particular when frictional cycle is repeated, its torque value gradually changes showing an upward curve, which makes a sudden up-swing when sodium temperature has reached 540 °C and thus the frictional force goes up more than two fold.

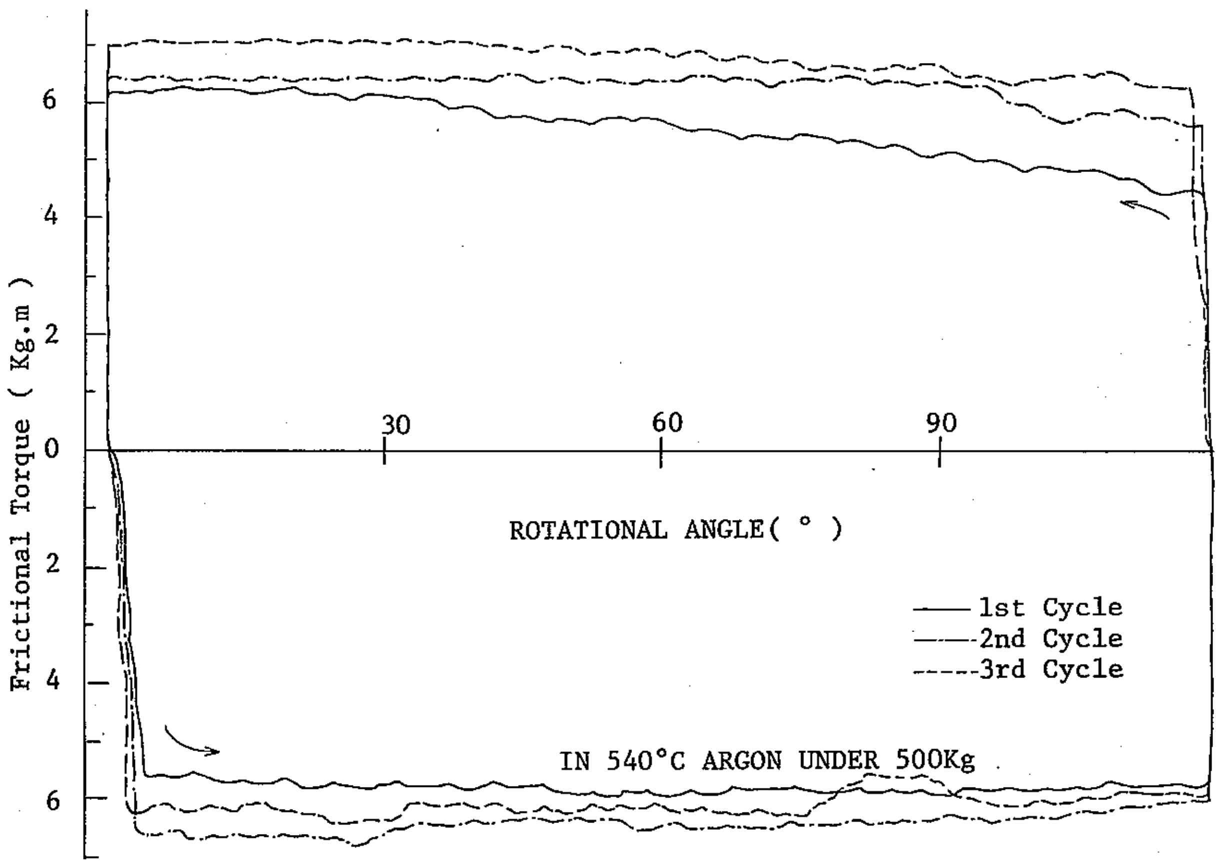
After this test in 540 °C sodium, the test specimen on the sliding side was raised by 10mm to separate it from the contact face of its partner material, and was exposed to the flowing sodium at 540 °C for about 16 hours to give it a flushing effect. The results of the friction test performed to the above materials after such sodium flushing are as shown by Fig. 6. After this flushing effect, unstability of frictional behavior has increased, and with the repetition of frictional sliding, the frictional torque value has increased. Especially, the frictional torque value at the return cycle showed a sudden rise indicating quite deteriorating behavior.

It may be said that, of these friction test data, such materials which show a stable friction performance and low frictional torque values, i.e., such Stellite No. 6 materials in their same combination showing stable behavior in the room temperature frictional test, and indicating the lowest frictional coefficient in the in-sodium test at 280 °C, are the most satisfactory frictional resistant materials. Fig. 7 represents the comparative graph of test results at various temperatures and under various loads plotted by computing out the frictional coefficients from the torque values at the time when the first cycle made a 60° rotary sliding motion as given in Figs. 5 and 6.

In the test in 540 °C sodium, although there is possibility of being affected by the various frictional cycle, the test under the lower loads of 100 and 250Kg, frictional coefficients presented close to 0.9, and under other test conditions, values were stable little affected by load. From the comparison of these frictional coefficients, the following items have been made clear:




AT ROOM TEMP UNDER 1000Kg




IN 540°C ARGON UNDER 500Kg

Fig-5 Results of Friction on Stellite No.6

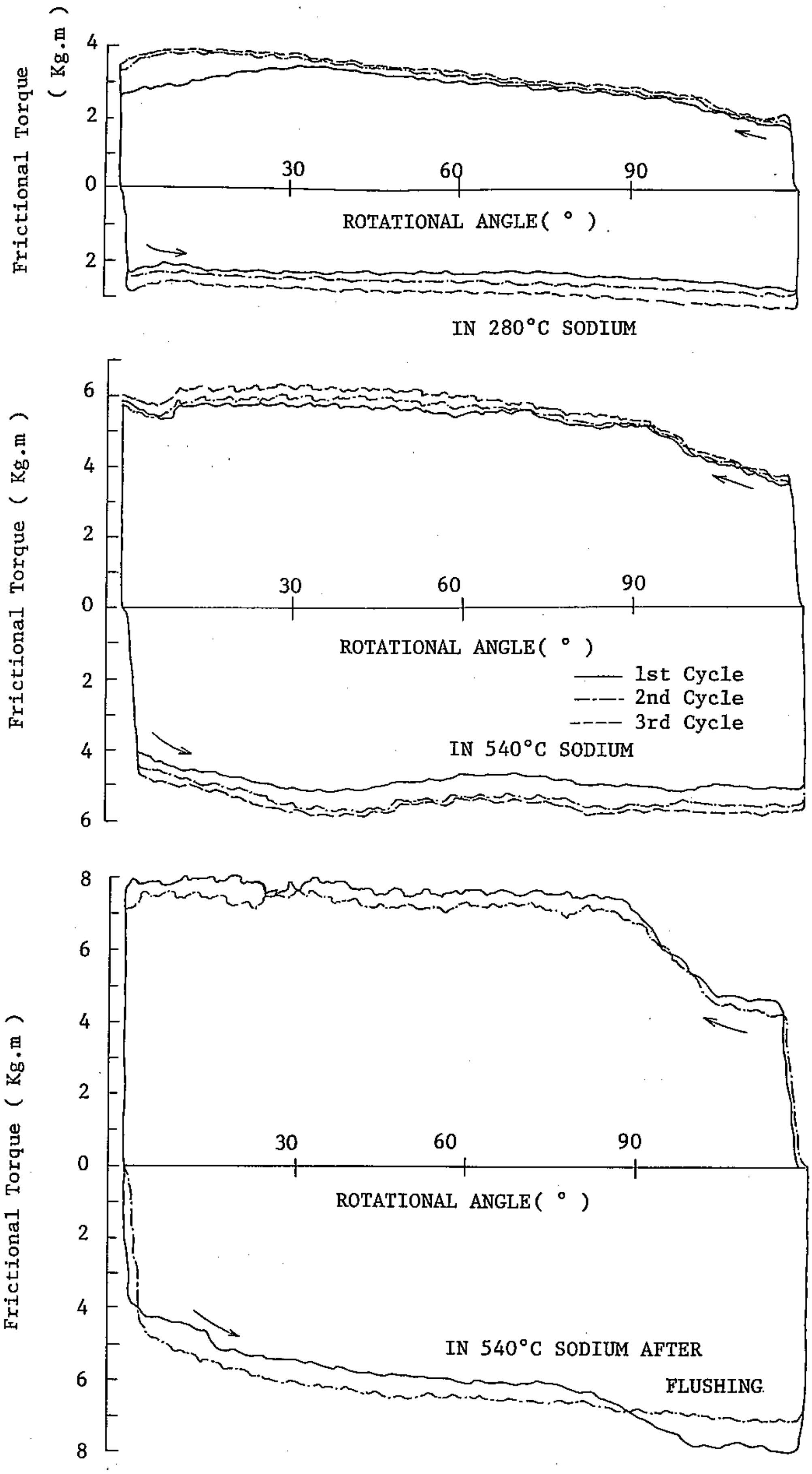



Fig-6 Results of In-Sodium Friction Test on Stellite No. 6 under 500Kg Nominal Load

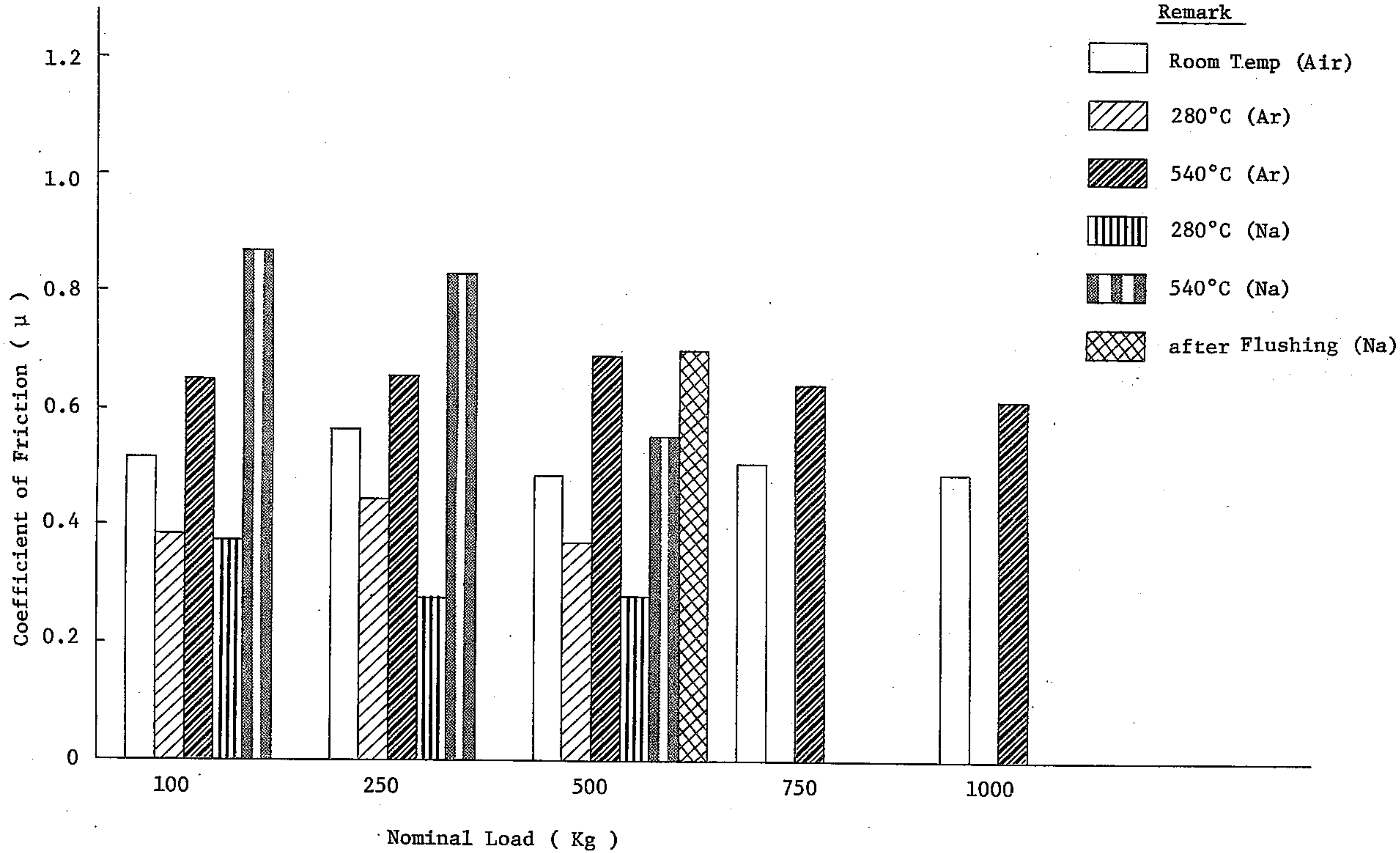



Fig.-7 Changes of Frictional Coefficient on Stellite No.6 in Different Environment

(1) Frictional coefficient values from the room temperature test test were stable from the low load to the high load (1,000Kg) showing 0.5 ~ 0.6 values, while from the test in high temperature argon at 540 °C, frictional coefficients showed high values (0.6 ~ 0.9) indicating somewhat unstable frictional behavior than in the case of the room temperature test.

(2) Both in-argon and in-sodium tests, frictional coefficients rose following the rise of temperature.

(3) Especially, the in-sodium test at 540 °C showed higher frictional coefficient under the lower load of 100Kg and lower frictional coefficient under higher loads.

(4) By sodium flushing, frictional coefficient rose by almost 30%. Further evaluation on this sodium flushing effect may be necessary from the longer hours side in the future.

Photo-2, 3 and 4 represent the external appearances and metallographic test of specimens after exposed to friction tests in various environments. As every test shows an off-setting frictional specimen, sliding traces are indicated uniform over all its circumferential contacting area. The surface conditions of these specimens presented different states according to environments in which they had been tested. In particular, the materials tested in high temperature argon presented traces of plastic flow. Also, the frictional sliding areas of those materials subjected to high temperature test in-sodium were examined by scanning electronmicroscope, and deposition of abrasion particles on the frictional sliding faces was observed. The abrasion particle deposition is shown by Photo-5. This microstructure does not represent the frictional sliding faces, but it is estimated to represent the abrasion particle excoriated faces as the result of repeated frictional movements.

3-2 Frictional Performance of Colmonoy No. 6 Same Material

Figs. 8 and 9 respectively show the friction test data of frictional performance of Colmonoy No. 6 same material combination in various environments. The nominal load for each of these tests was 500Kg. The comparison of data of the test at room temperatures and the one in argon environment with the data of in-sodium test revealed that the frictional torque value of in-sodium test was lower than those of the room temperature and in-argon tests. Especially in the case of this combination of material, its torque value is lower as higher is the sodium temperature, and by high temperature sodium flushing, even its frictional torque value is made lower unlike in the case of the above mentioned Stellite No. 6.

As for frictional behavior, it is more unstable in the argon environment, while it is most stable in room temperatures, though its frictional torque value is high. After high temperature sodium flushing, the first frictional cycle showed the lowest torque value and increasing the frictional cycles to 2 and 3 cycles, the torque value also increased, and frictional behavior became rather unstable. Anyhow, the frictional torque showed the lowest value in this environment. The sum up of the torque values at the time of the $60^{\circ}$ rotation in the first friction cycle as shown in Figs. 8 and 9 and the frictional coefficients worked out from the actual measured values of load is as shown by Fig. 10. Although the data show some discrepancies from those in Figs. 8 and 9 according to the actual measured values of load, the overall trend is almost similar. Summarizing the frictional performances of the Colmonoy No. 6 same material combination from the graphic data, the following items may be accounted:

(1) Frictional performance at room temperatures is stable, and shows almost identical frictional coefficient value from low load to high load (1,000Kg). This value, however, is relatively high, in the range of 0.6 ~ 0.7.

(2) In argon, particularly at 540 °C, frictional behavior is unstable, while the frictional coefficient under the nominal load of 250Kg has reached as high as 0.94.

(3) In sodium, frictional coefficient is lower than in the case of in-argon and at room temperature, and is little affected by sodium temperatures.

(4) Even by sodium flushing, its frictional coefficient value does not rise unlike the above mentioned Stellite No. 6 same material combination, and it somewhat declined after 540 °C sodium flushing.

Then, the materials after these tests were subjected to metallographical test of their frictional surfaces, the results of which are shown by Photoes-6, 7 and 8 respectively. It is seen from these photographs that the external appearances of these materials after test show uniform sliding traces on the identical circumferential areas. Also from the microstructures as observed by electron microscope, it is known that, the material surfaces present entirely different as pects between those tested in sodium and those in high temperature argon. Those tested in argon show on their frictional surface traces of plastic flow, while those tested in sodium present deposition of some sorts of oxide products on their frictional surfaces suggesting some kind of frictional effect worked on them.

The frictional behavior after application of 540 °C sodium flushing showed the lowest torque value at the first frictional cycle, and its torque value increased as frictional cycle was repeated. From this fact, it is conceivable that a certain type of film layer serving as lubricant is formed on the frictional surface, and that this film has a trend to be destroyed at each frictional cycle. This trend, though not so conspicuous, has also been noticed with other materials. In carrying out future friction tests, further research and studies on the effect of this film (which is produced or formed by dipping materials in sodium) will be necessary (for instance, to find out the critical destroying conditions of the film).

## 3-3 Frictional Characteristic of Chromium Carbide Same Material

In respect of chromium carbide materials, we have obtained several evaluations as the results of our past experiments, and various factors can be considered. This kind of material is also one of those materials having large variation. It has been known from the past experiment that, among the affecting factors, Ni-Cr elements contained in it as a binder material occupy a large share of such affecting factors(3). That is, although even this kind of material is expected to be very effective and useful if used in a right way, when misused, or under inadequate use conditions, it will involve a big risk. For these reasons, its use must be judged from the results of various experiments. The present friction test by repetition of motion is performed by entirely a new technique different from the conventional methods. Figs. 11 and 12 show the results of our friction tests in various environments on LC-1C same material combination. The surface of LC-1C material was coated and brush finished retaining its original rough surface.

The frictional behavior of this material combination was stable at room temperatures, and showed extremely low frictional torque values, while in high temperature argon, this torque values drastically increased. In sodium, it showed more stable frictional behavior than in argon, and indicated slightly lower frictional torque values. From the frictional torque values at the rotational angle 60° at the first cycle and the real measured load in the present experiment, the frictional coefficients in various environments were computed out and plotted into graphs as shown in Fig. 13. Similarly, tests were performed on the LC-1C material by grind-polishing its surface to make its surface roughness below 1 , of which results are as shown by Fig. 14, and the frictional coefficients under various loads are shown in Fig. 15.

The sum up of these results is given as follows:

(1) At room temperatures, frictional behavior is very stable without relation to surface roughness, and also frictional coefficients are low (0.3 ~ 0.4).

(2) In argon, frictional coefficients are high (0.6 ~ 0.9), and as temperature rises, they come down quite unlike the case of stellite and colmonoy materials.

(3) In sodium, the surface with rough B.F finish shows more stable frictional behavior than that of G.F polish, and frictional coefficients are almost identical at 280 °C, while in sodium at 540 °C, the surface with G.F finish shows a higher frictional coefficient value above 1.2.

(4) When sodium temperature goes up, both materials of B.F. and G.F finish show higher frictional coefficients. And, by

application of 540 °C sodium flushing, their frictional coefficients also go up. In particular, the material of G.F finish shows a larger change.

From the above described frictional behaviors, consideration was given for the judgement of suitable material combinations, and their structural and surface changes were also examined from the metallographic observation. Photoes. 9 ~ 12 show the results of these metallographic analysis. In this case, though microstructural changes from the final load test may be considered, even with this material combination, each material surface presents different conditions between in-sodium test and in-argon test. In-sodium test, hardly any frictional sliding trace is presented on the contact area in friction. This can also be observed on the tested material of which surface was applied with G.F polish. (Those wear traces observed on the non-frictional surface are those which were left at the time of the finish-up of the material.)

In the case of B.F, the dark area on this microstructure shows the place where sodium had gathered and served as lubricant, while the area showing metallic luster is estimated to have received the impact of load. The electron microscopic analysis as shown by Photo-11 indicates such optical microstructure white spots as dark spots, and in these dark spots, there are noticed fine granular objects. In Photo-12, the dark microstructural area on the material with G.F finish-up as observed by optical microscope is much reduced after friction. From this, the material with G.F finish is estimated to have higher frictional resistance. With the material with B.F finish, these ratios are thought to have important bearing with frictional behaviors. But with respect to this type of LC-1C material,

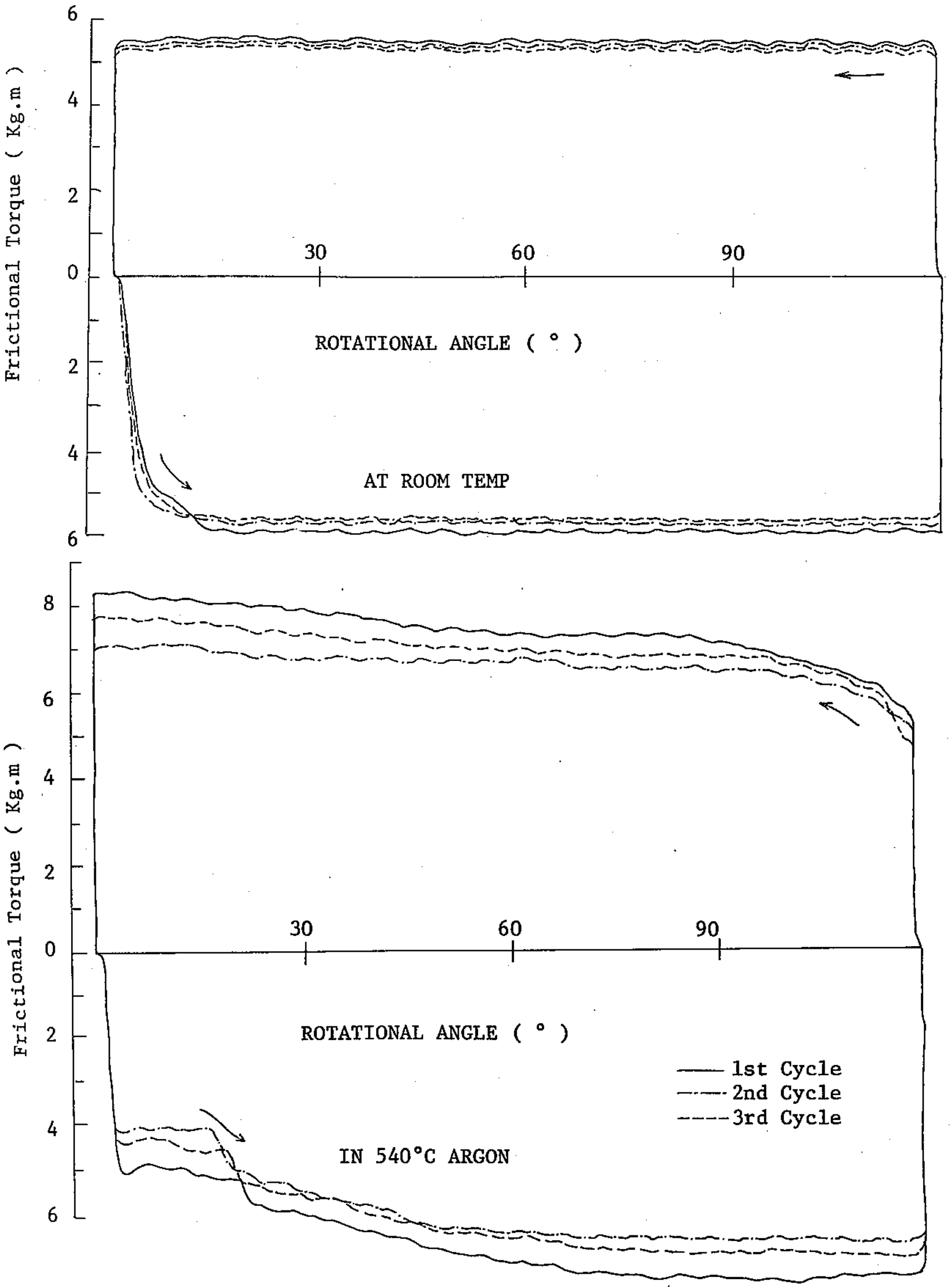



Fig-8 Results of Friction Test on Colmonoy No.6 vs. Colmonoy No.6

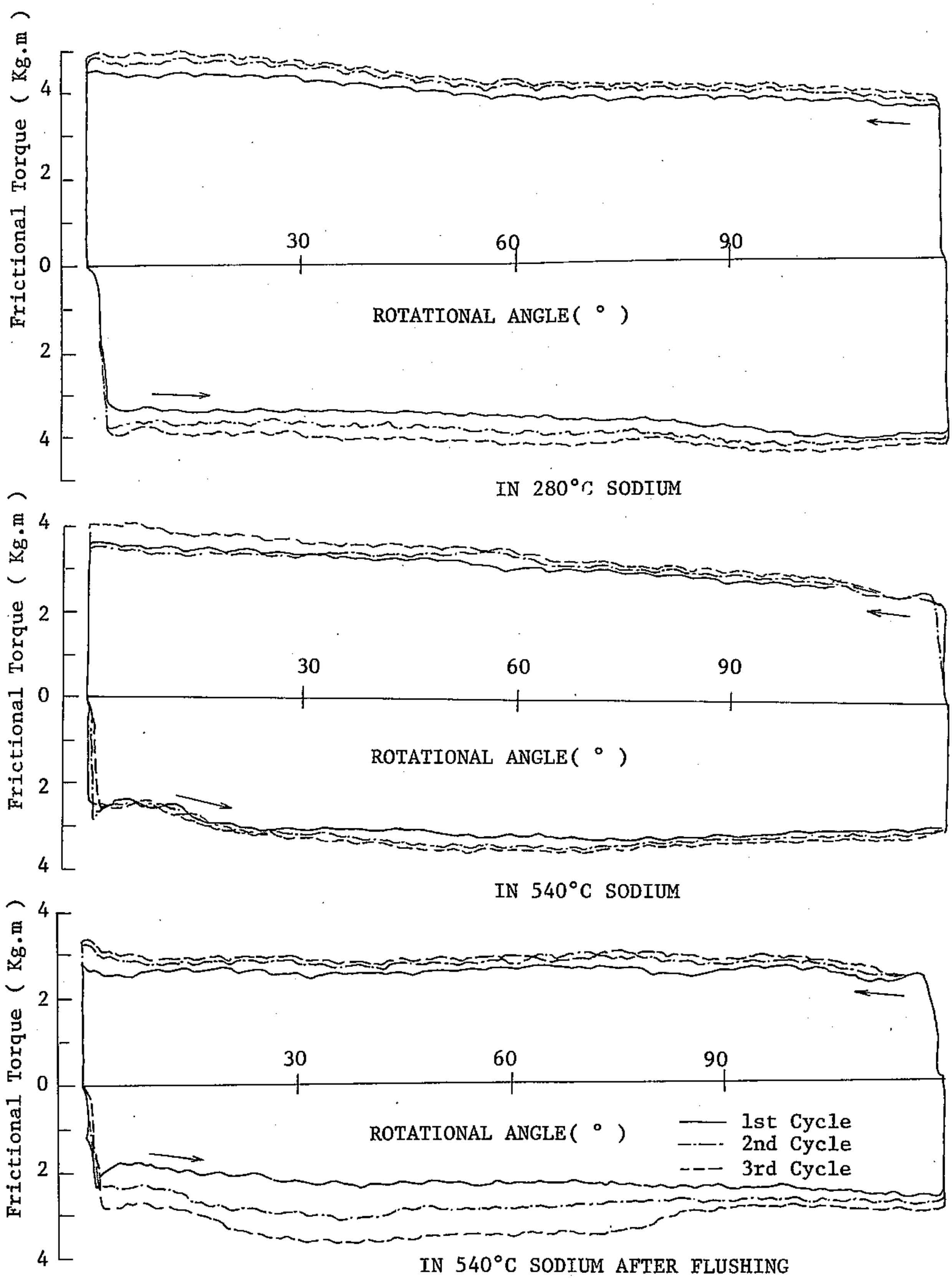



Fig.-9 Results of In-Sodium Friction Test on Colmonoy No.6 Homogeneous Material Combination under 500Kg Nominal Load.

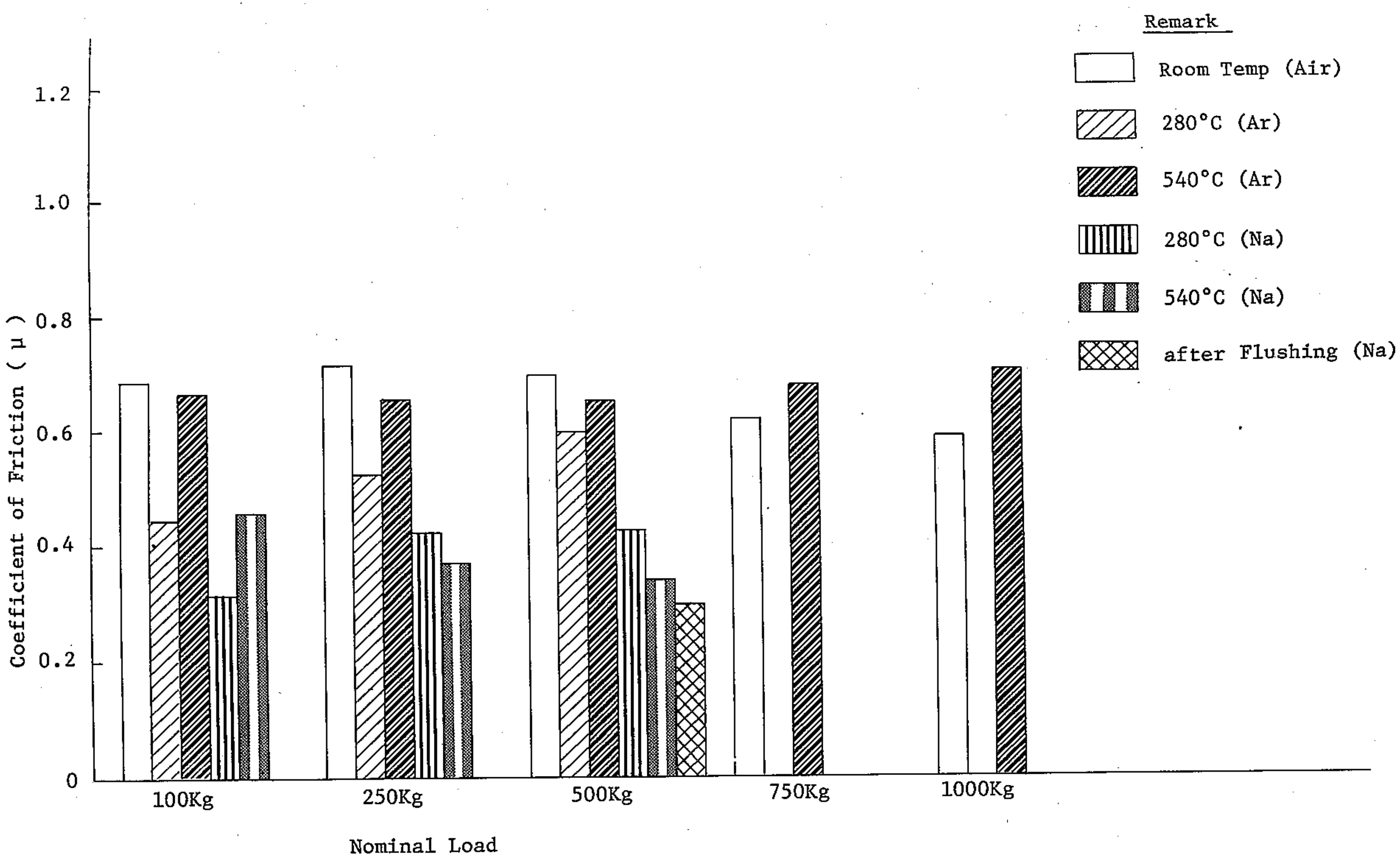
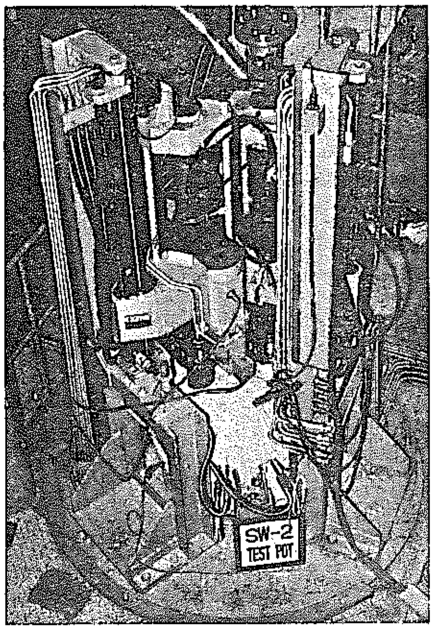
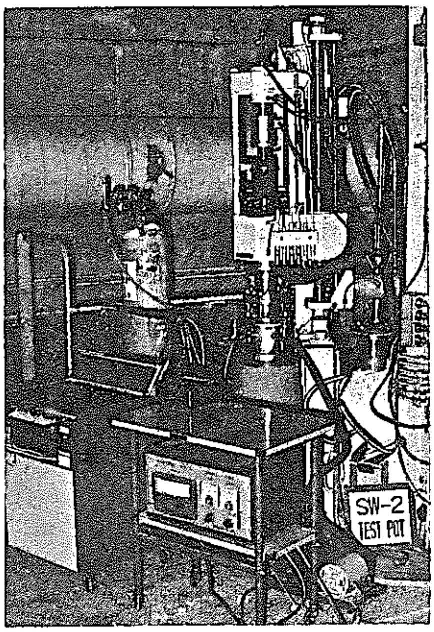


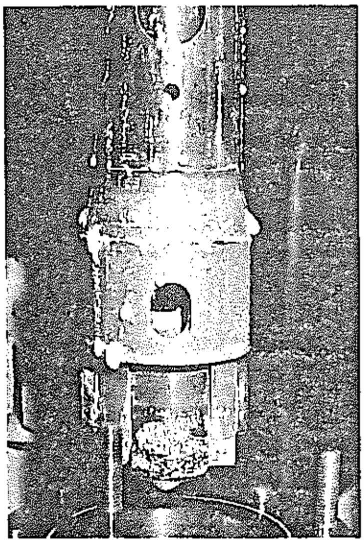

Fig.-10 Changes of Frictional Coefficient on Colmonoy No.6 in Different Environments



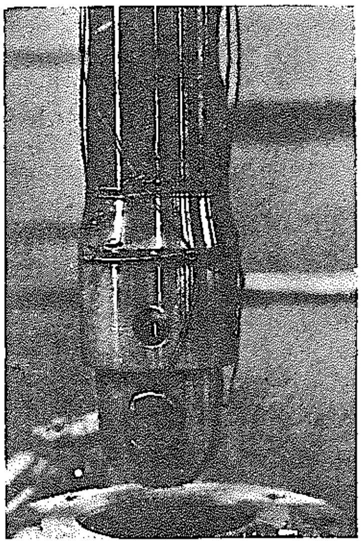

Testing Equipment in Sodium



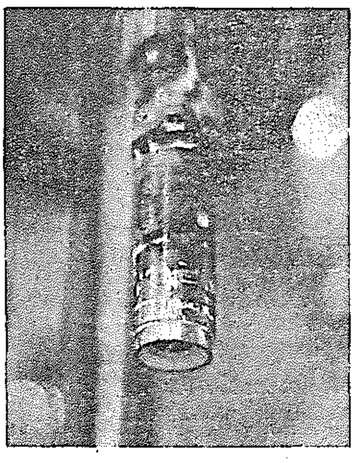

Testing Equipment in Argon



After Tested in Sodium



After Tested in Argon



Rotor Specimen after Tested in Sodium

Photo-1 External Appearances of Specimens and Testing Equipment after In-Sodium and In-Argon Tests

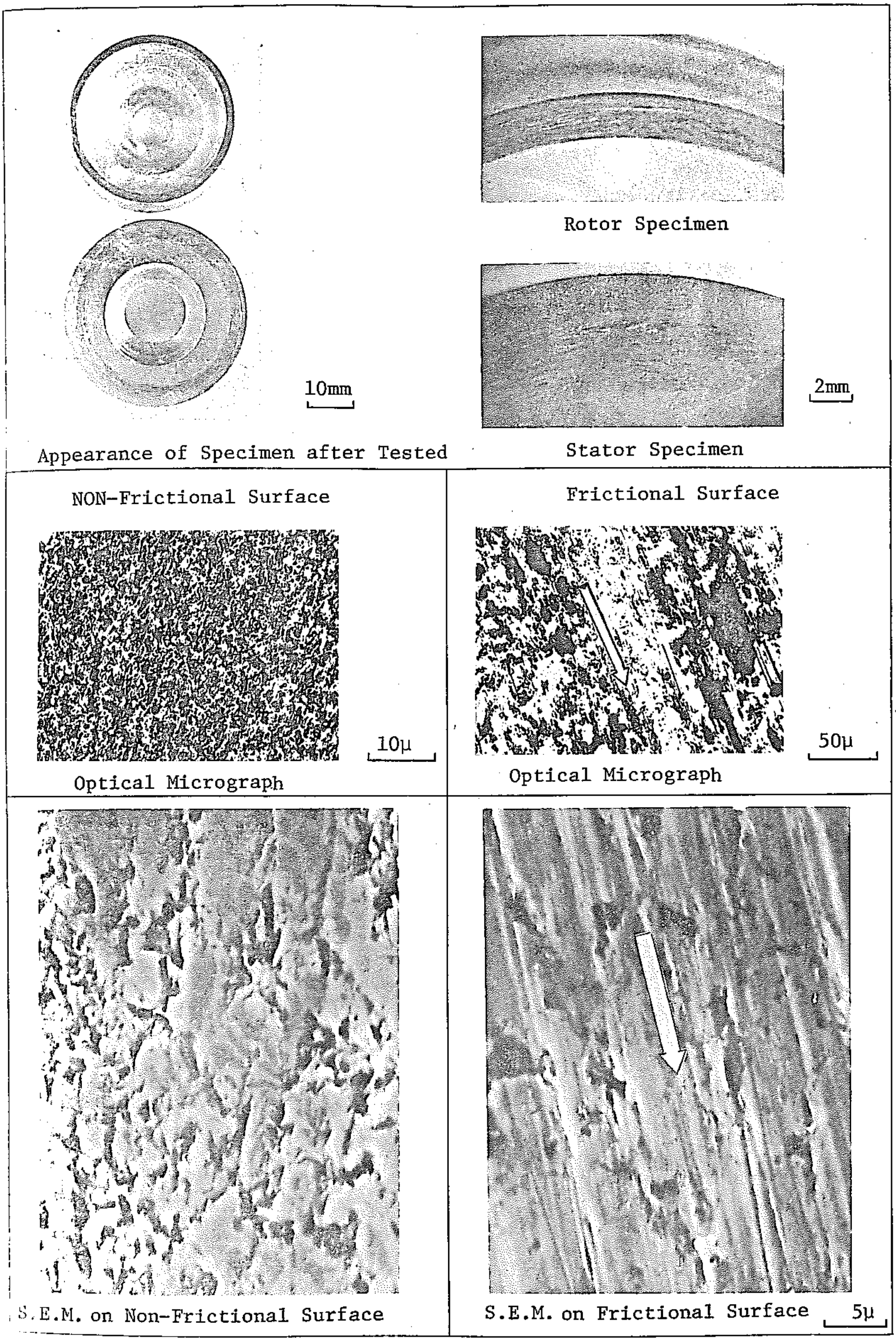



Photo-2 Metallographic Analysis of the Stellite No.6 after tested at Room Temp.

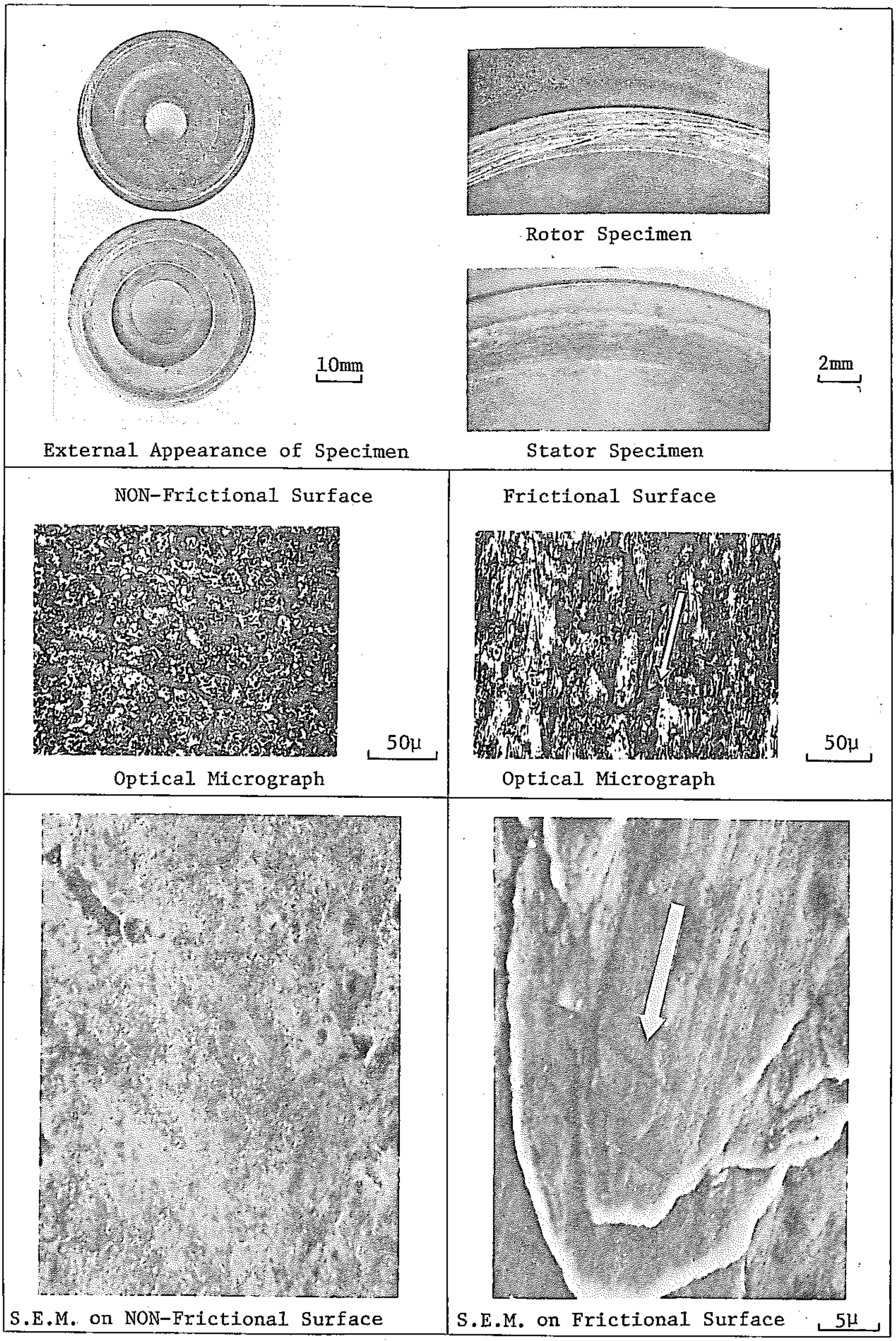
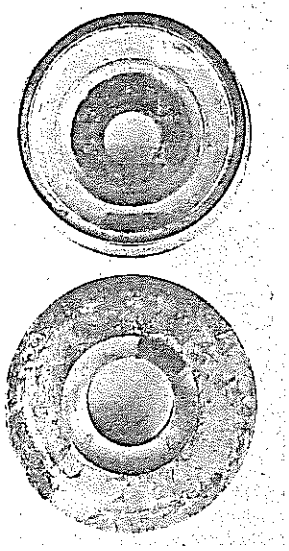
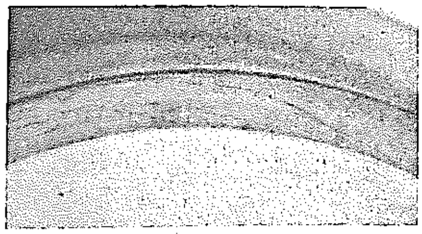



Photo-3 Metallographic Analysis of Stellite No.6 after Tested in 540°C Argon



10mm

External Appearace of Specimen

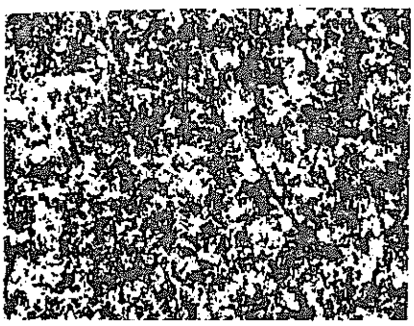


Rotor Specimen

2mm

Stator Specimen

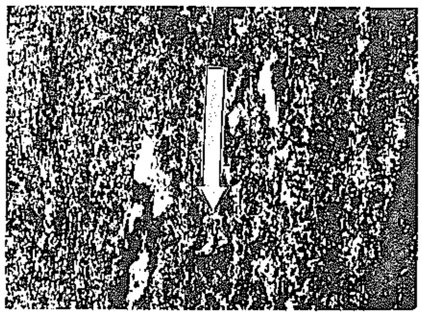
NON-Frictional Surface



50μ

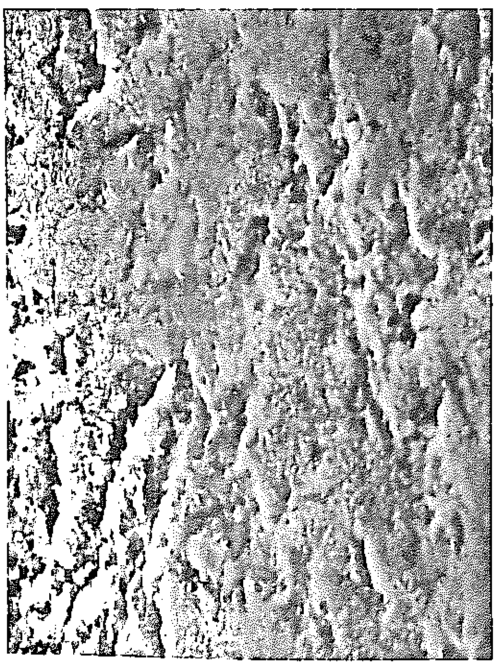
Optical Micrograph

Frictioal Surface



100μ

Optical Micrograph



S.E.M. on the Non-Frictioal Surface

S.E.M. on the Frictional Surface 5μ

Photo-4 Metallographic Analysis of Stellite No.6 after Tested in 540°C Sodium

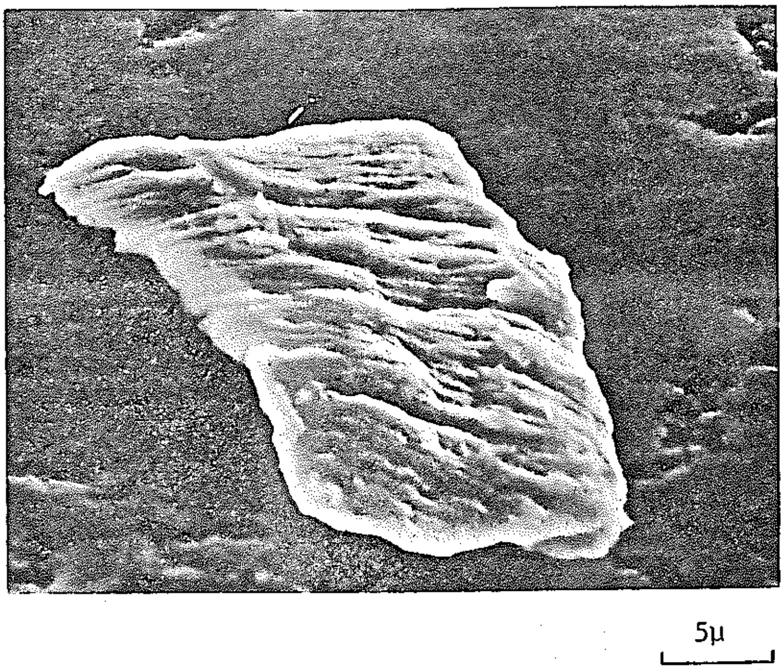
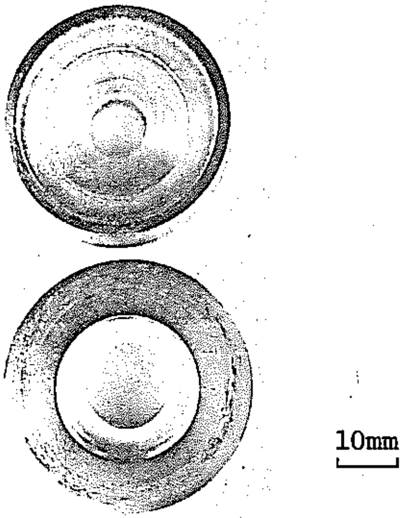
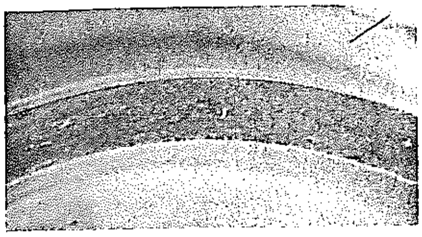


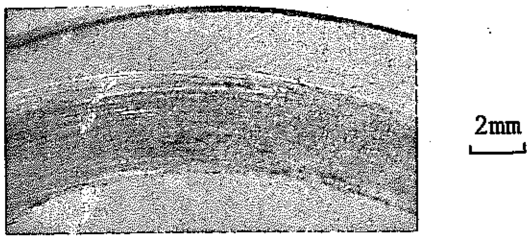

Photo-5 S.E.M. of the wear particle on Frictional Surface of Stellite No.6




External Appearance of Specimen

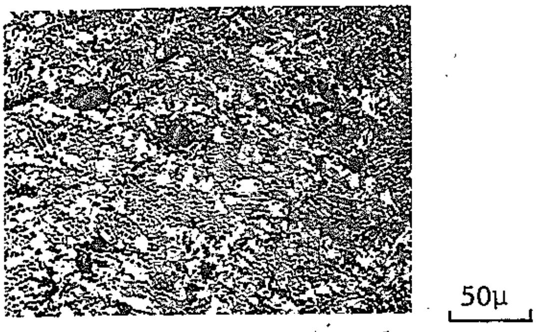


Rotor Spcimen



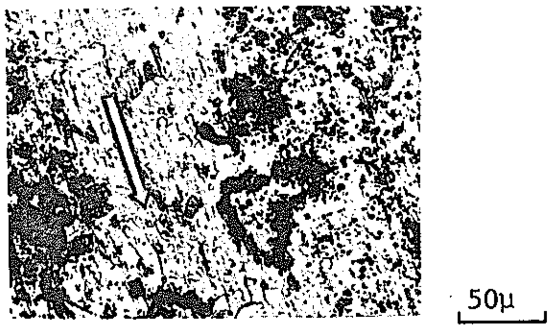

Stator Specimen

NON-Frictional Surface

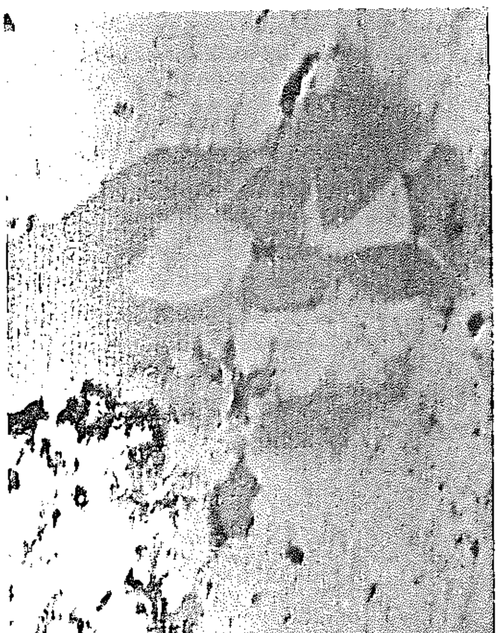



Optical Micrograph

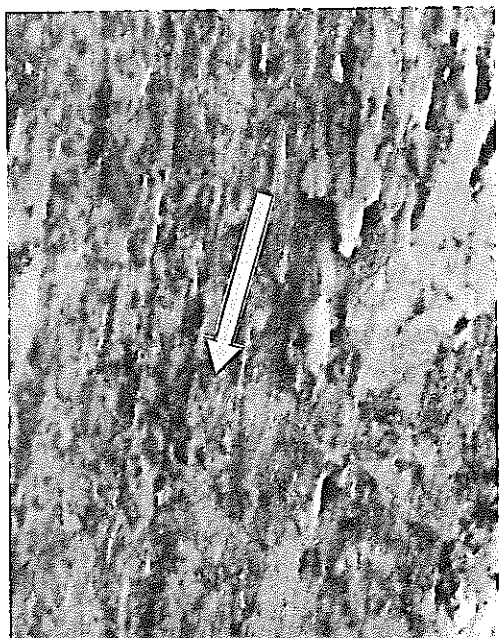
Frictional Surface




Optical Micrograph

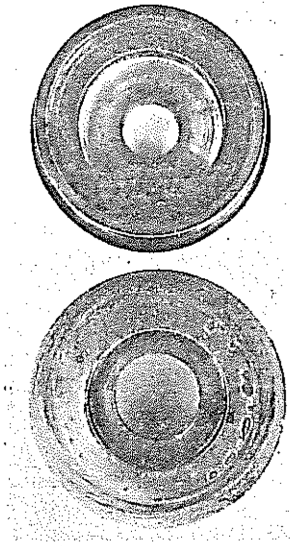


S.E.M. on the Non-Frictional Surface



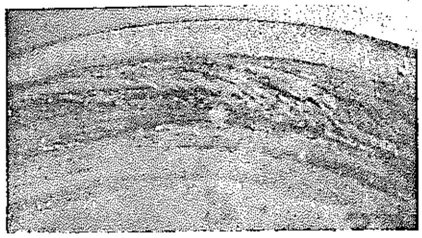

S.E.M. on the Frictional Surface

Photo-6 Metallographic Analysis of Colmonoy No.6 after Tested at Room Temp




External Appearance of Specimen

Rotor Specimen

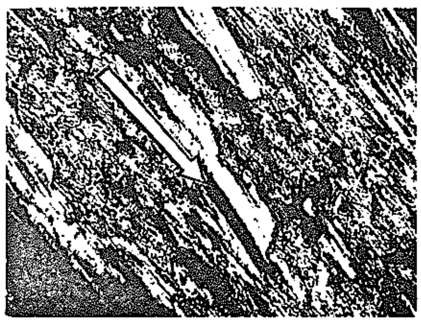



Stator Specimen

NON-Frictional Surface

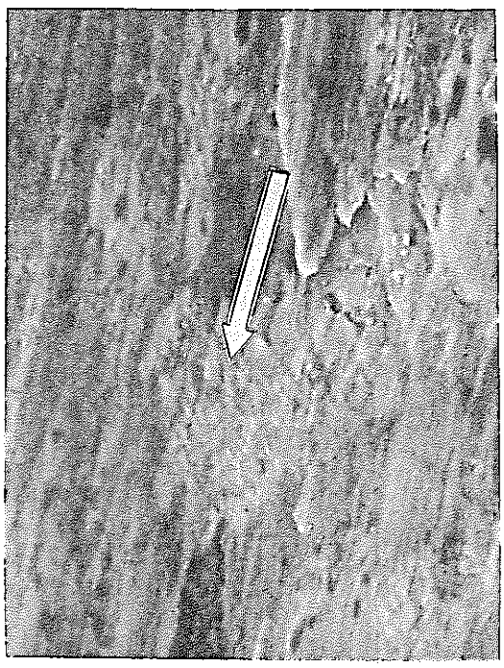

Optical Micrograph

Frictional Surface



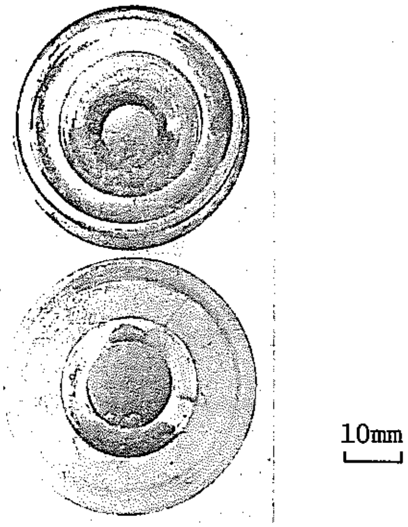

Optical Micrograph

S.E.M. on the Non-Frictional Surface



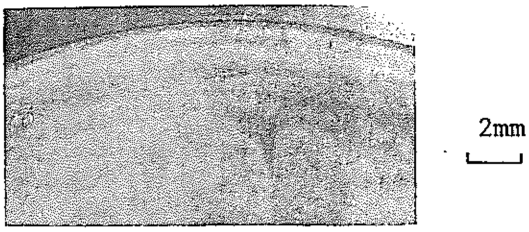
S.E.M. on the Frictional Surface 5μ

Photo-7 Metallographic Analysis of Colmonoy No.6 after Tested in 540°C Argon



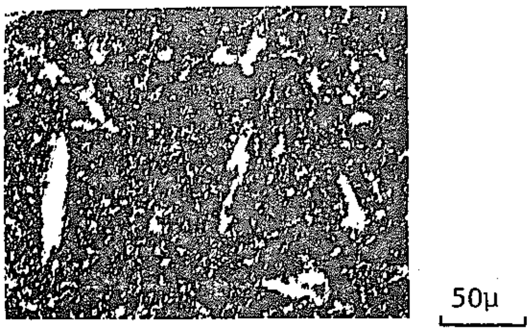

External Appearance of Specimen

Rotor Specimen




Stator Specimen

NON-Frictional Surface

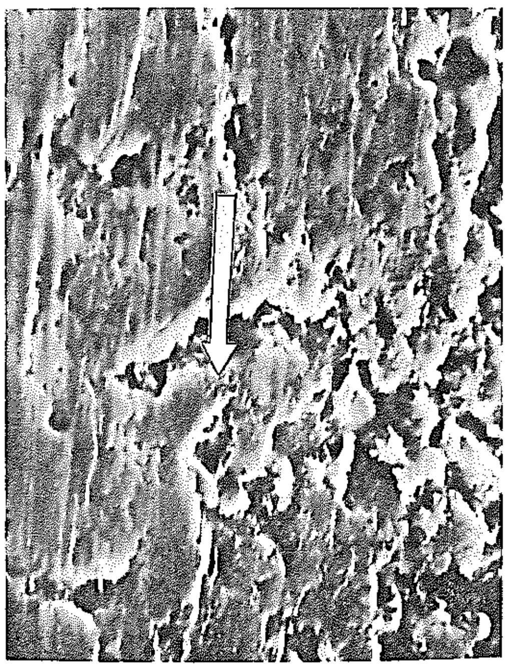



Optical Micrograph

Frictional Surface


Optical Micrograph

S.E.M. on the Non-Frictional Surface



S.E.M. on the Frictional Surface 5μ

Photo-8 Metallographic Analysis of Colmonoy No.6 after Tested in 540°C Sodium as various affecting factors are considerable, it is difficult to make any overall judgement. It is, therefore, thought necessary to work evaluations from the results of long term in-sodium experiments and of accelerated tests selecting stainless steel material as the mating material in the future.

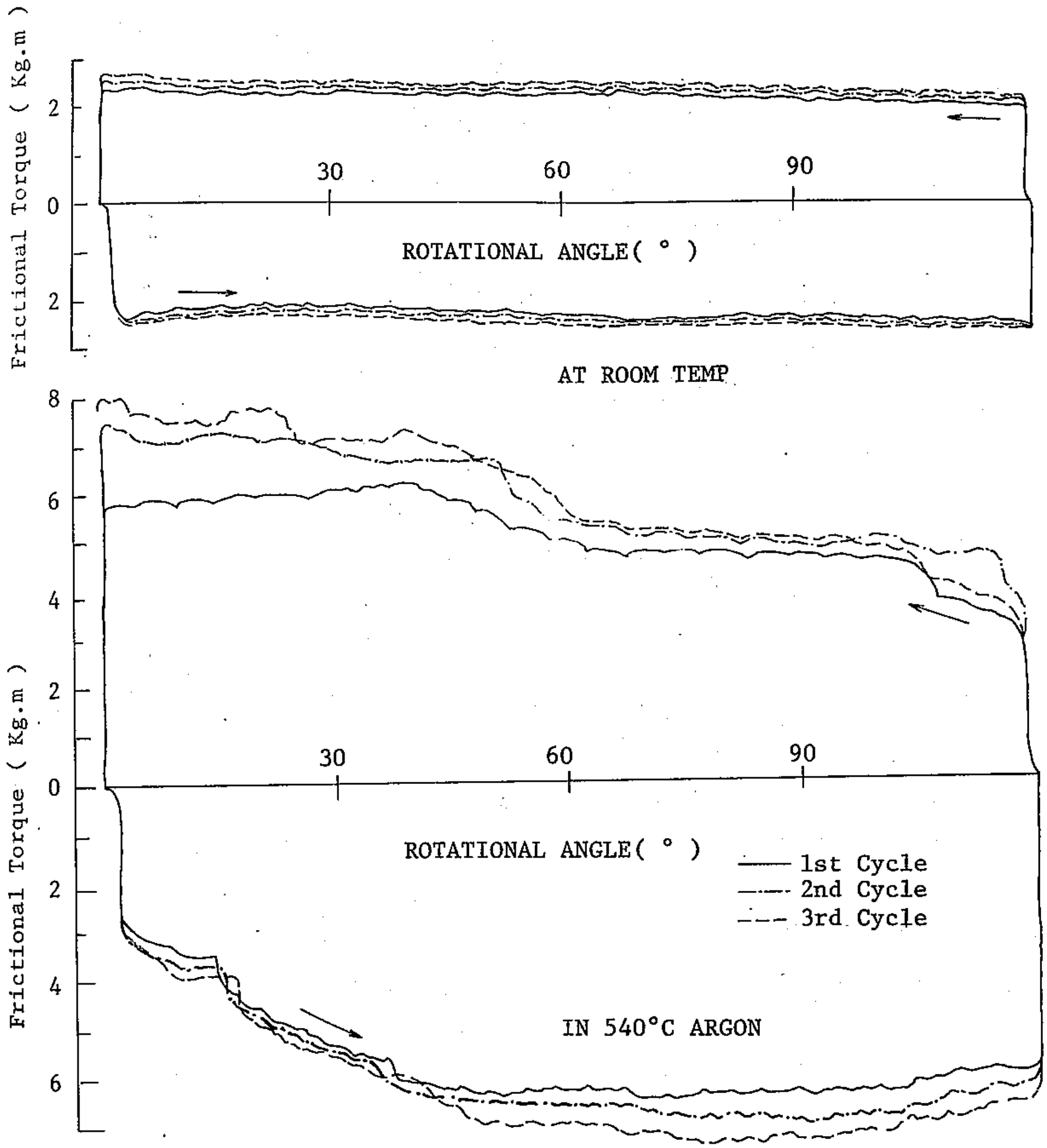



Fig-11 Results of Friction Test on LC-1C ( B.F ) VS LC-1C ( B.F )

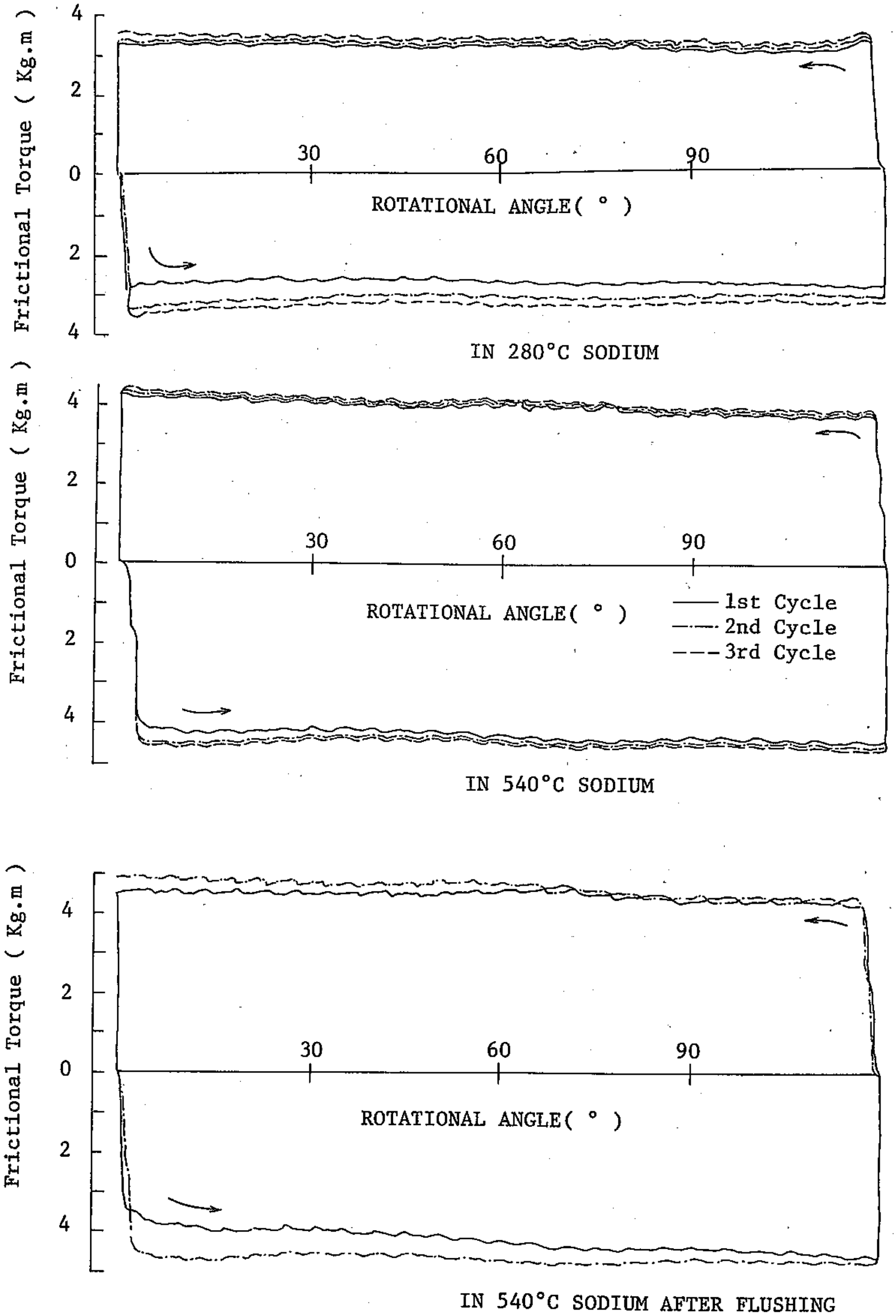



Fig-12 Results of In-Sodium Friction Test on LC-1C (B.F) Homogeneous Material Combination under 500kg Nominal Load

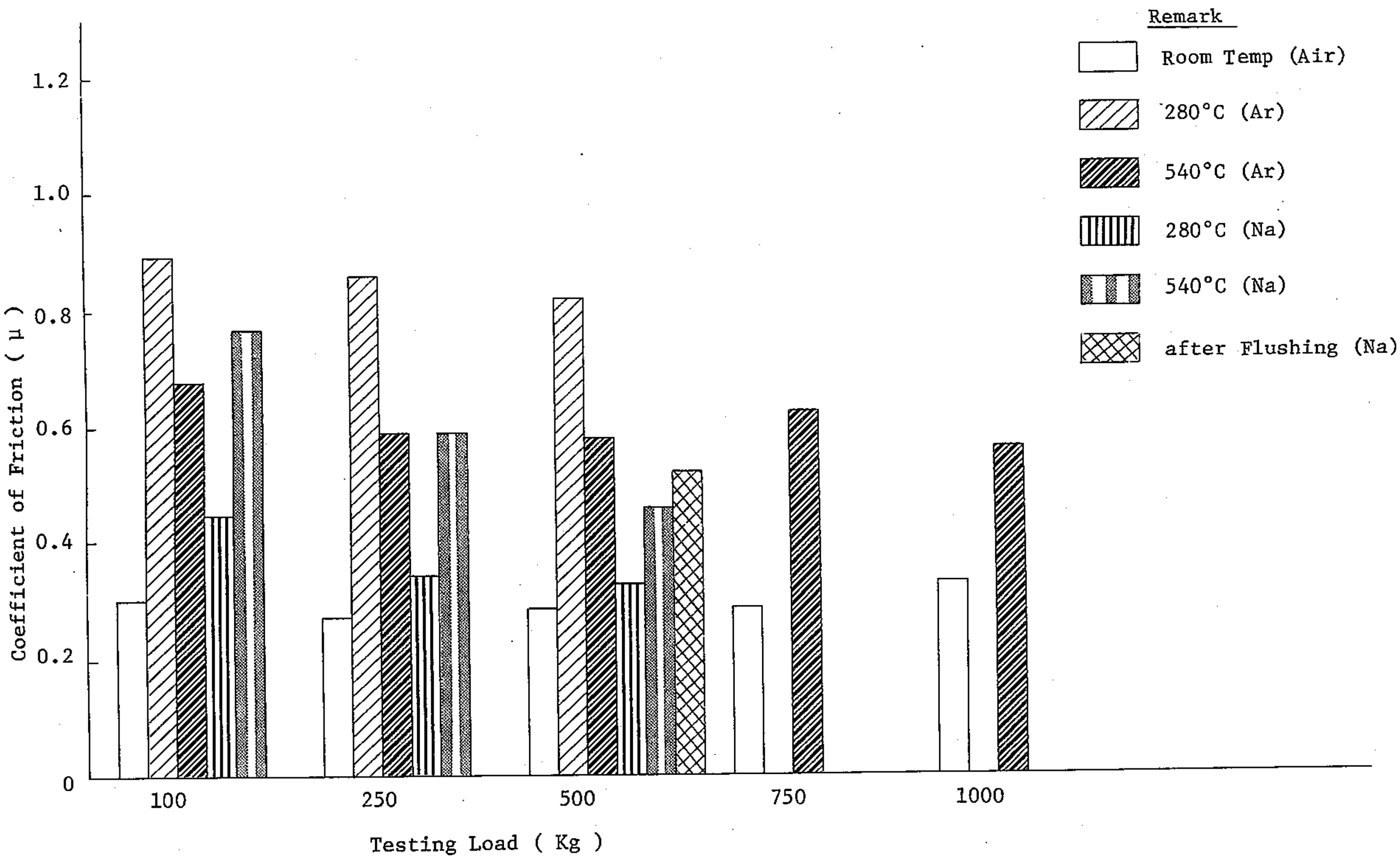



Fig-13 Changes of Frictional Coefficient on LC-1C (B.F) in Different Environments

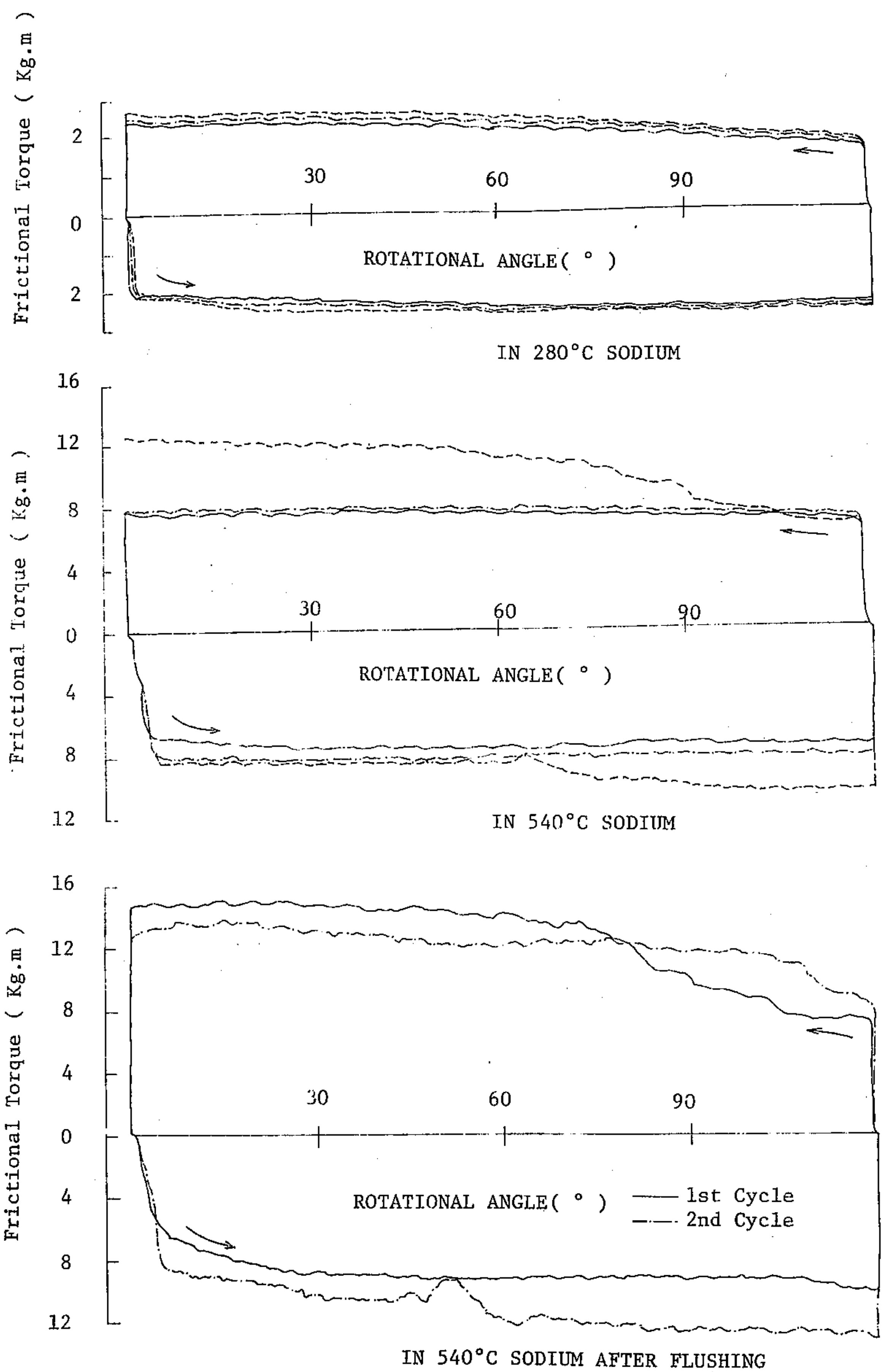



Fig-14 Results of In-Sodium Friction Test on the LC-1C (G.F) under 500kg Nominal Load

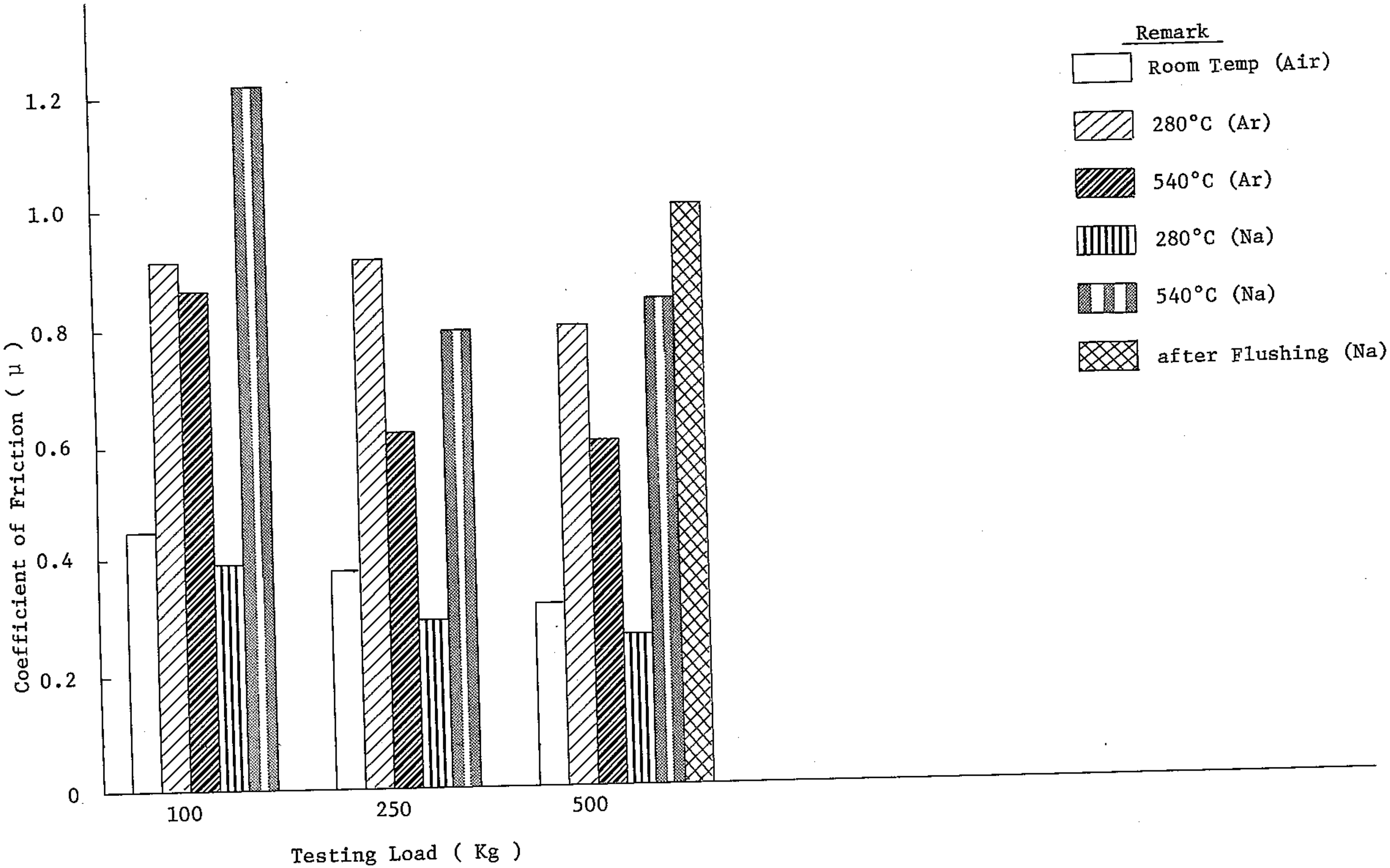
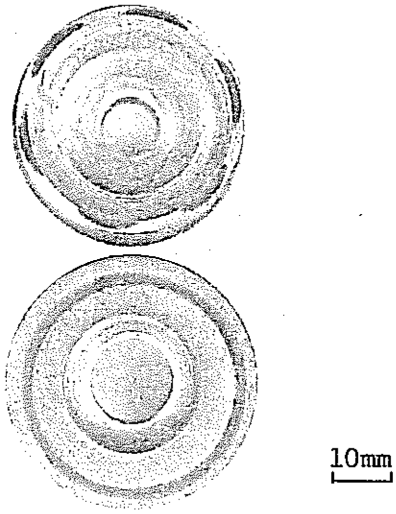
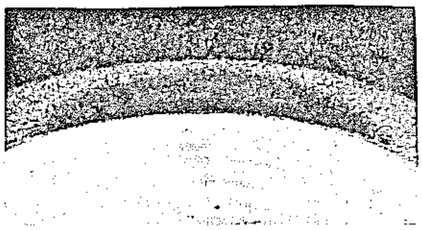



Fig.-15 Changes of Frictional Coefficient of LC-1C (G.F) Material in Different Environments



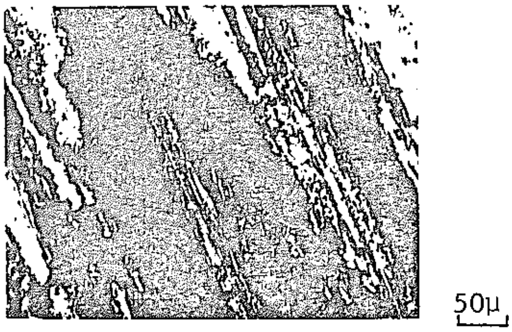

External Appearance of Specimen



Rotor Specimen

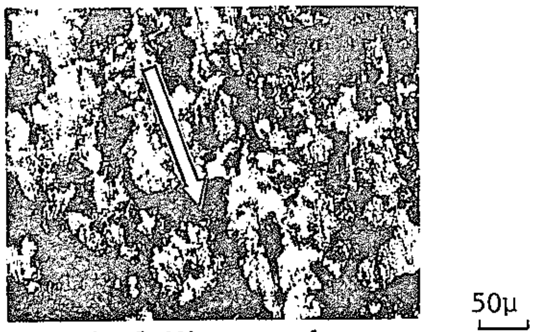

Stator Specimen

NON-Frictional Surface

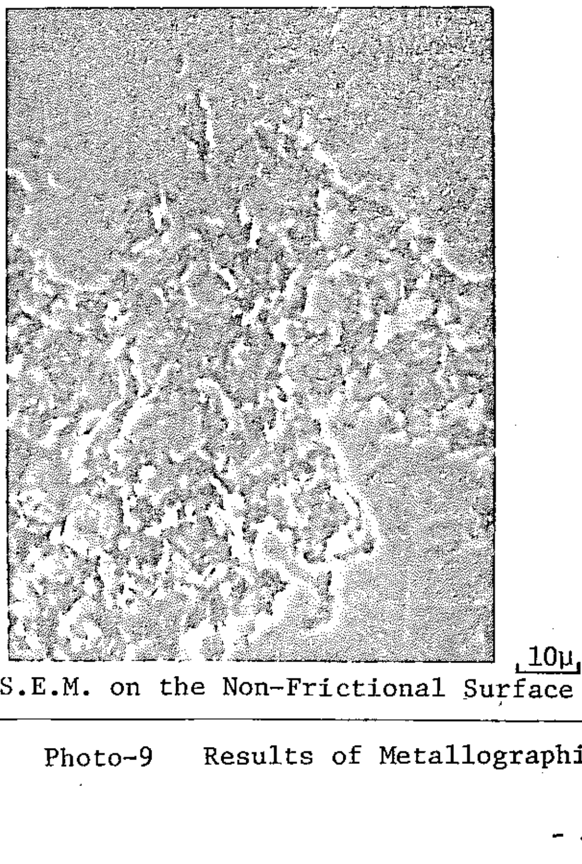



Optical Micrograph

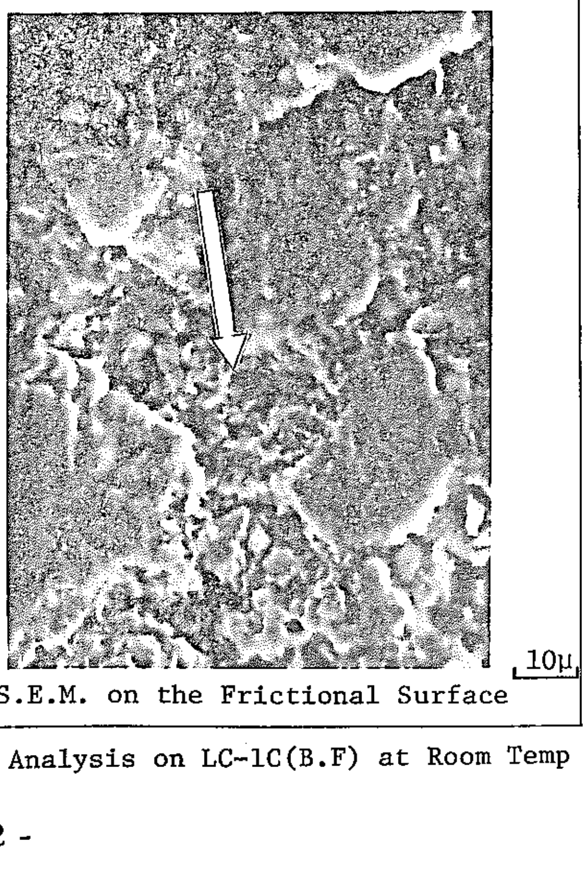
Frictional Surface




Optical Micrograph




S.E.M. on the Non-Frictional Surface




S.E.M. on the Frictional Surface

Photo-9 Results of Metallographic Analysis on LC-1C(B.F) at Room Temp

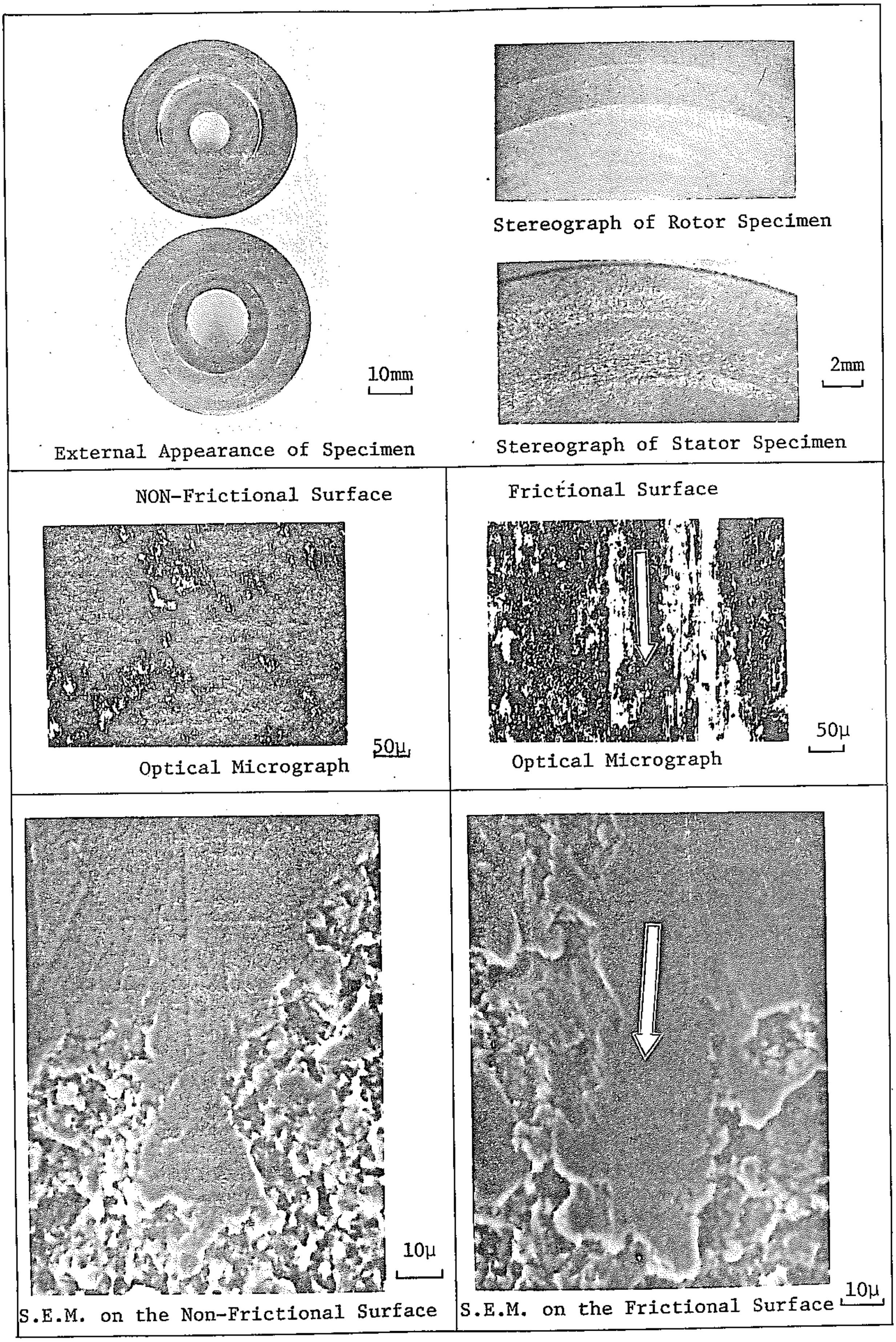



Photo-10 Results of Metallographic Analysis on LC-1C(B.F) in 540°C Argon

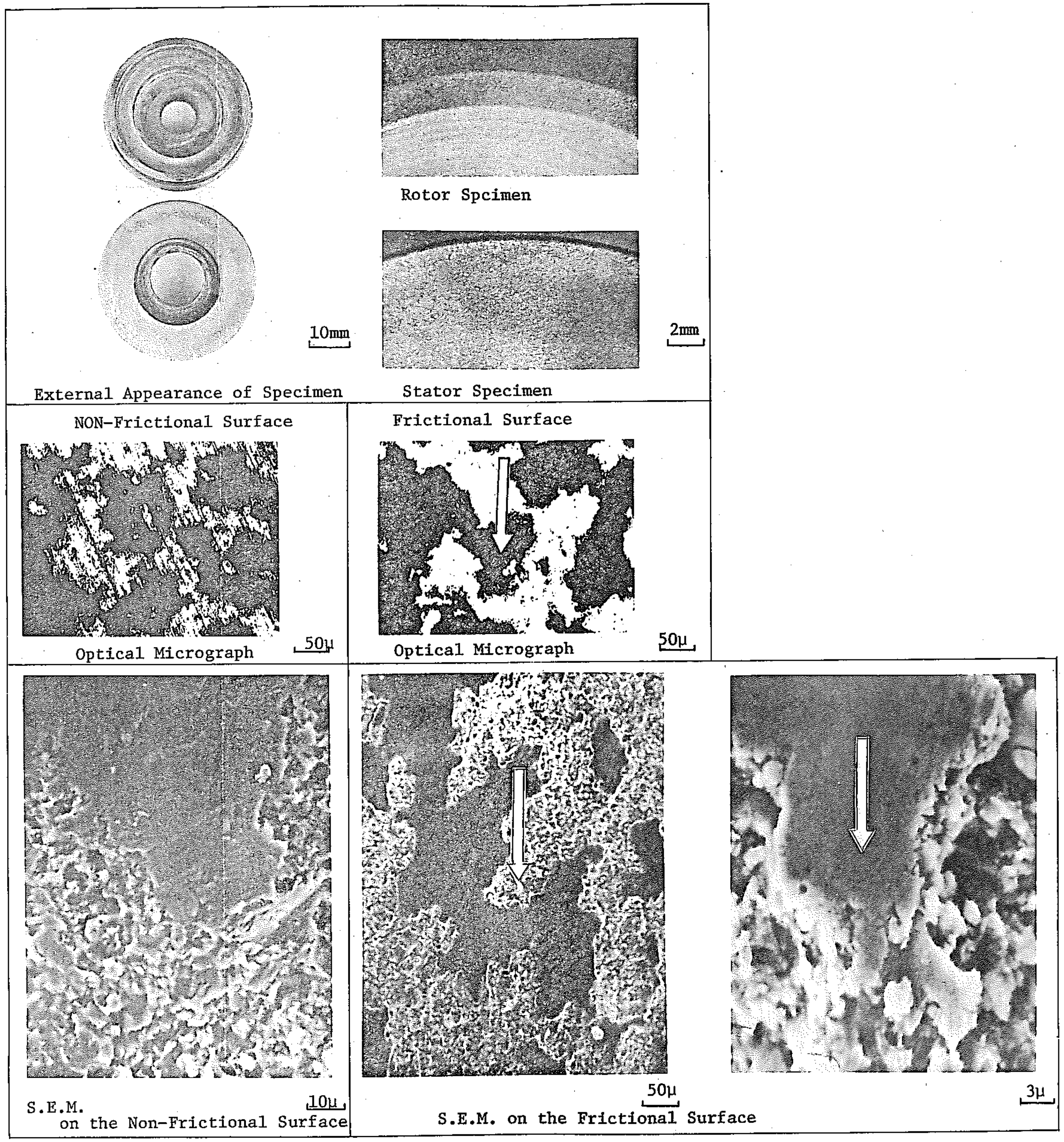



Photo-11 Results of Metallographic Analysis on LC-1C(B.F) Material in 540°C Sodium

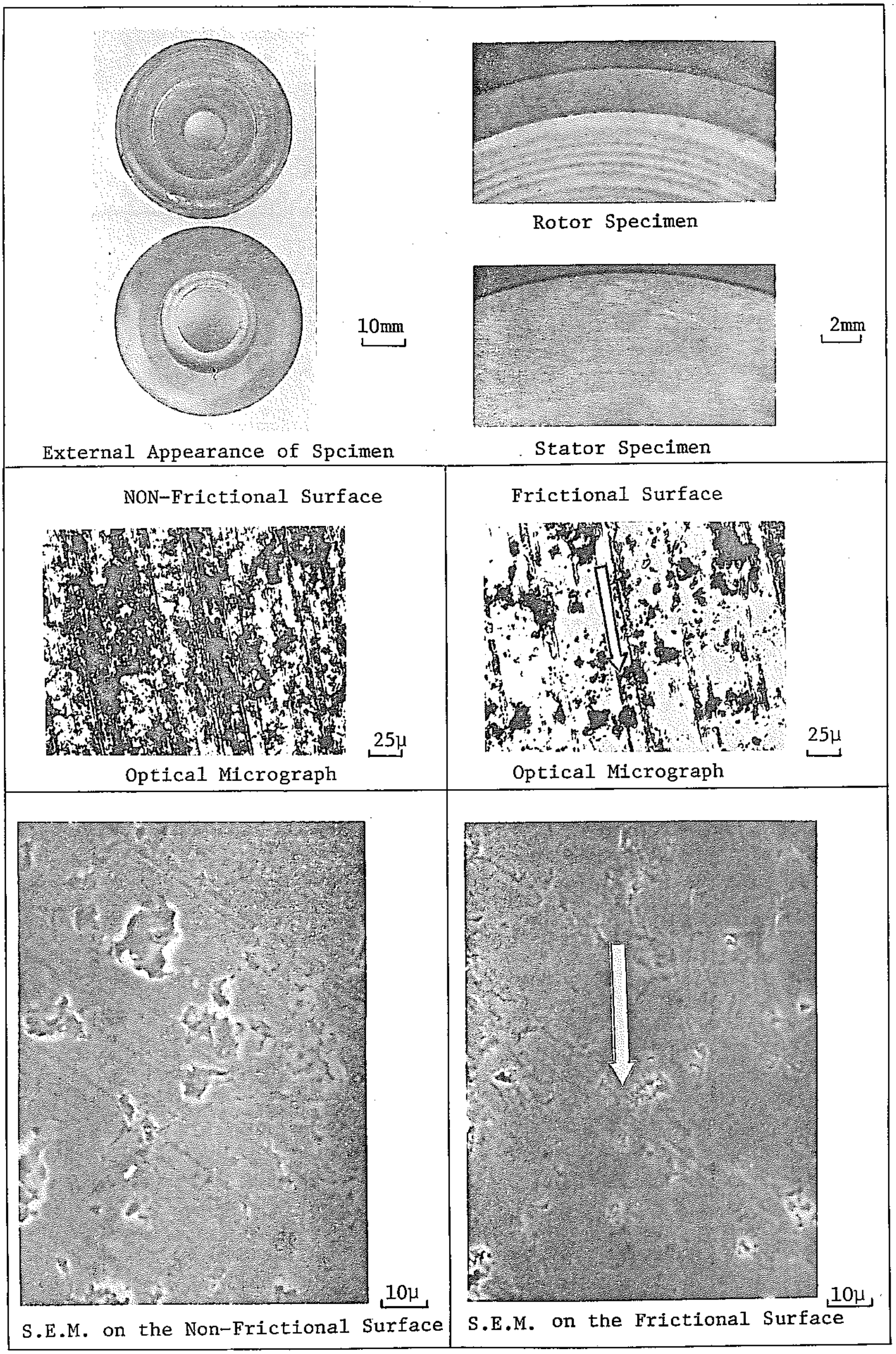



Photo-12 Results of Metallographic Analysis on LC-1C(G.F) in 540°C Sodium

## 3-4 Frictional Characteristic of Hard Cr-Plated and Inconel Materials

Besides the tests on Stellite No. 6, Colmonoy No. 6 and chromium carbide materials in various environments and their subsequent comparison as described in the preceding pages, the specimens of Hard Cr-plated and Inconel 718 material which is widely employed for contacting and sliding sections in-sodium were exposed to in-sodium tests for subsequent material evaluation. Figs.16 and 17 show the results of test on Hard Cr-plated and Inconel 718 material. Hard Cr-plated material showed quite unstable frictional behavior. Especially, in 540 °C sodium, its frictional torque value at the initial sliding was low, while with th eprogress of sliding motion, it came to indicate increased torque value, and in some regions, the value reached highest showing two times as high as in other regions. Thus, the combination of Hard Cr-plated materials showed unstable frictional behavior suggesting use of this kind of material combination would involve a great risk. As shown by Fig. 17, the same material's combination of Inconel 718 presented stable frictional behaviors, and its frictional torque value increased when sodium temperature reached 540 °C. But it has been known that this combination is much more stable than in the case of Hard Cr-plated material combination. As Inconel 718 materials have been aged and hardened at high temperatures, it is thought that the frictional heat generated by material friction will make the surface of this kind of material overaging, over heated, and softened, and thus this will affect to the material's frictional performance thereafter.

This time, after subjecting the material to an in-sodium test at 540 °C, it was tested again in 280 °C sodium to compare the data with those at higher temperatures. In this case, although the effect of its various frictional cycle had to be considered, this Inconel 718 material showed 3-fold higher frictional torque values at the reduced temperature of 280 °C than at the increased temperature. Its frictional coefficients were calculated from these values and the actual measured load as shown in Figs. 18 and 19 respectively. Inconel 718 in 540 °C sodium showed increased frictional coefficients as its load applied heavier, and this phenomenon is estimated to have relation with the sudden rise of its frictional torque value at the time of temperature decline.

The following points have been made clear in respect of these materials:

(1) The same combination of Hard Cr-plated materials showed the highest frictional coefficient (0.8) in 280 °C sodium, while it declined in 540 °C sodium. Its frictional behavior was extremely unstable.

(2) Inconel 718 showed stable frictional behavior and low frictional coefficient (below 0.5) in 280 °C sodium, but this value rose in 540 °C sodium.

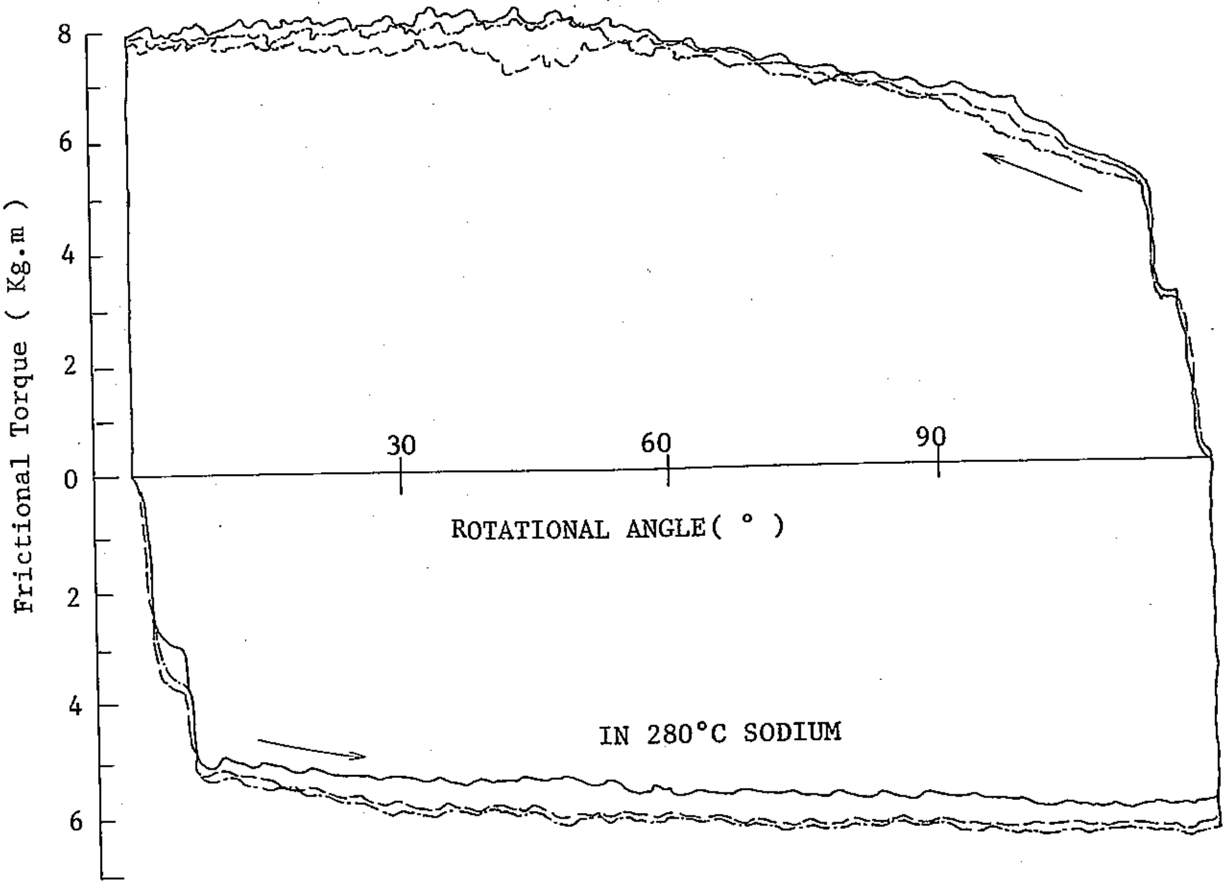
(3) Inconel 718 showed 3-fold high frictional coefficient (0.96) at the time the temperature was declining to 280 °C than the value at the time the temperature was ascending to 280 °C. This is assumed due to the effect of the aging of Inconel 718 material.

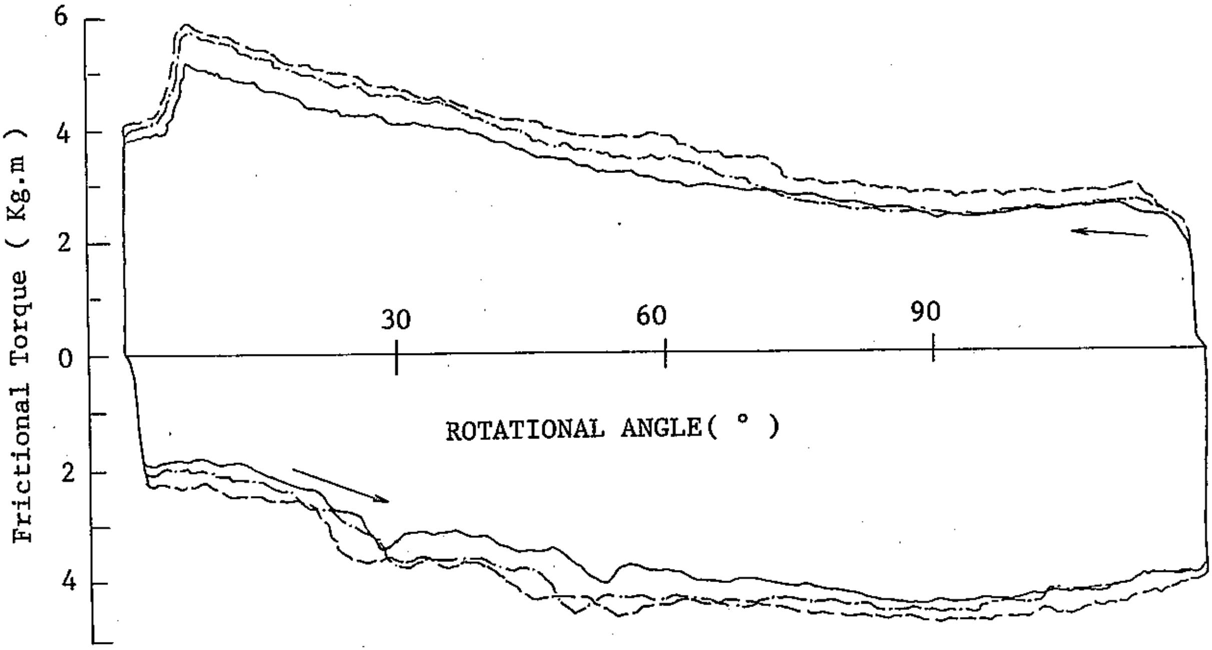
(4) Inconel 718 showed much smaller frictional coefficient in sodium than in argon at 280 °C, while at 540 °C, its frictional coefficient was about the same in either argon or sodium.

The frictional performances of Hard Cr-plated and Inconel 718 materials are described as above from the frictional coefficients.

Photoes- 13 and 14 represent the results of the metallographic tests. The Hard Cr-plated materials showed numerous cracks only by dipping them in sodium (as previously reported[3]), and these cracks further progressed by frictional (sliding) cycle. As the result, some of the frictional contact areas were observed presenting partial excoriation of Cr-plating. Sodium had deposited in these cracks and in the cavities caused by the excoriation of Cr plating and, thus it appeared to have served as a lubricating agent. But quite different from such cavities as seen on the surface of LC-1C (B.F) material as described in the previous pages, these sodium depositing cavities were thought to have been created at random, thus causing the material's frictional behavior to become very unstable. Also by partial excoriation of the plated layer, the friction contact surface of the mother material had exposed its type 316 stainless steel itself and thus increased its unstable behavior. From this, it is estimated that the inherent frictional behavior of the Hard Cr-plated material is poor and its coefficient is above 0.8. The Inconel 718 material after sodium dip presented dark surface by inter-metallic compounds which had made an age-precipitation. These inter-metallic compounds are judged to have worked as a load at either a low load or a low temperature, and the after-test frictional contact faces presented even, uniform sliding traces.

Fig. 20 represents the sum up of the sodium flushing effects on various materials. Various experiments are being conducted in foreign countries relating to sodium flushing effects.




IN 540°C SODIUM

Fig. -16 Results of In-sodium Friction Test on Hard Chrome Plated Material under 500Kg Nominal Load

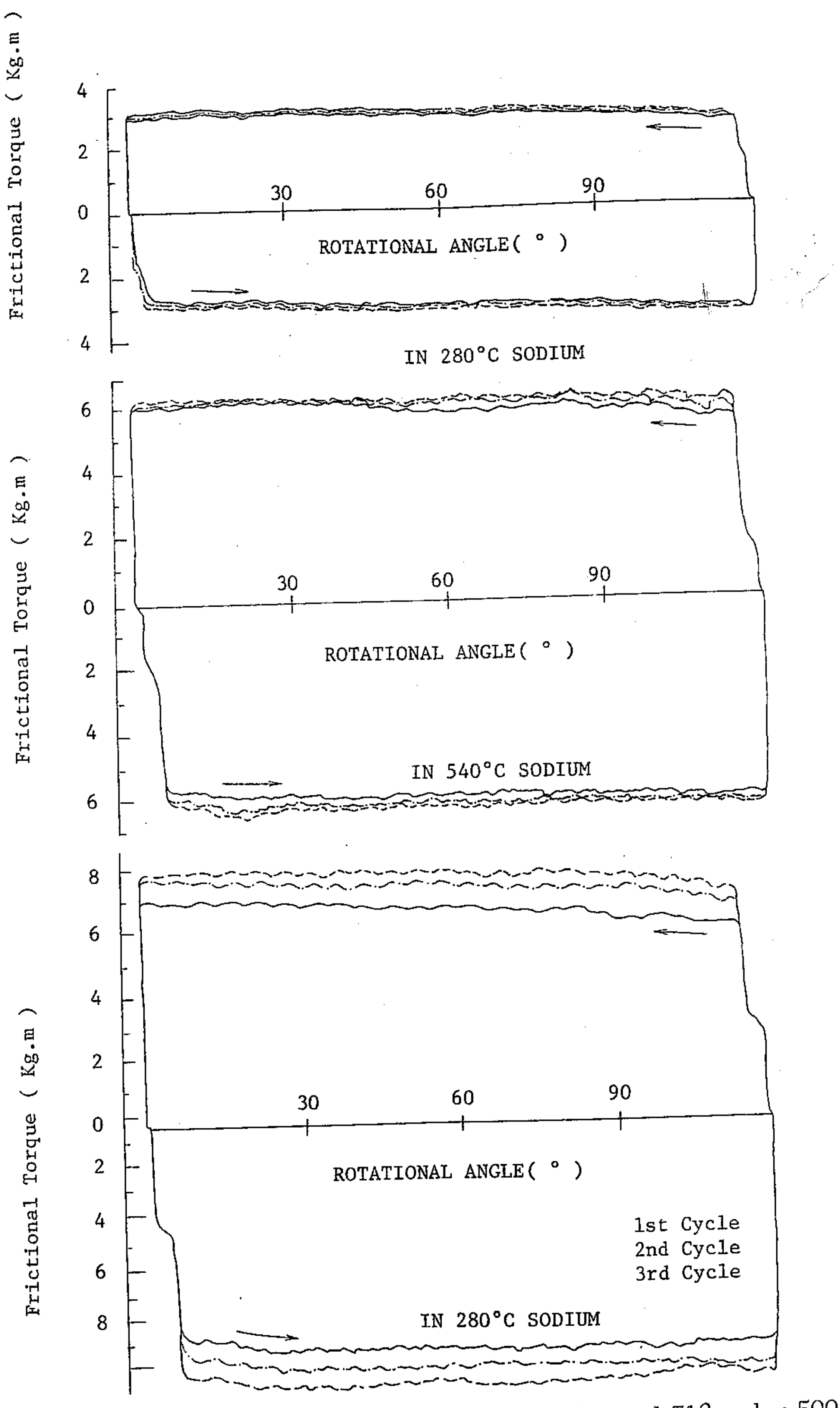



Fig.-17 Results of In-sodium Friction Test on Inconel 718 under 500Kg Nominal Load

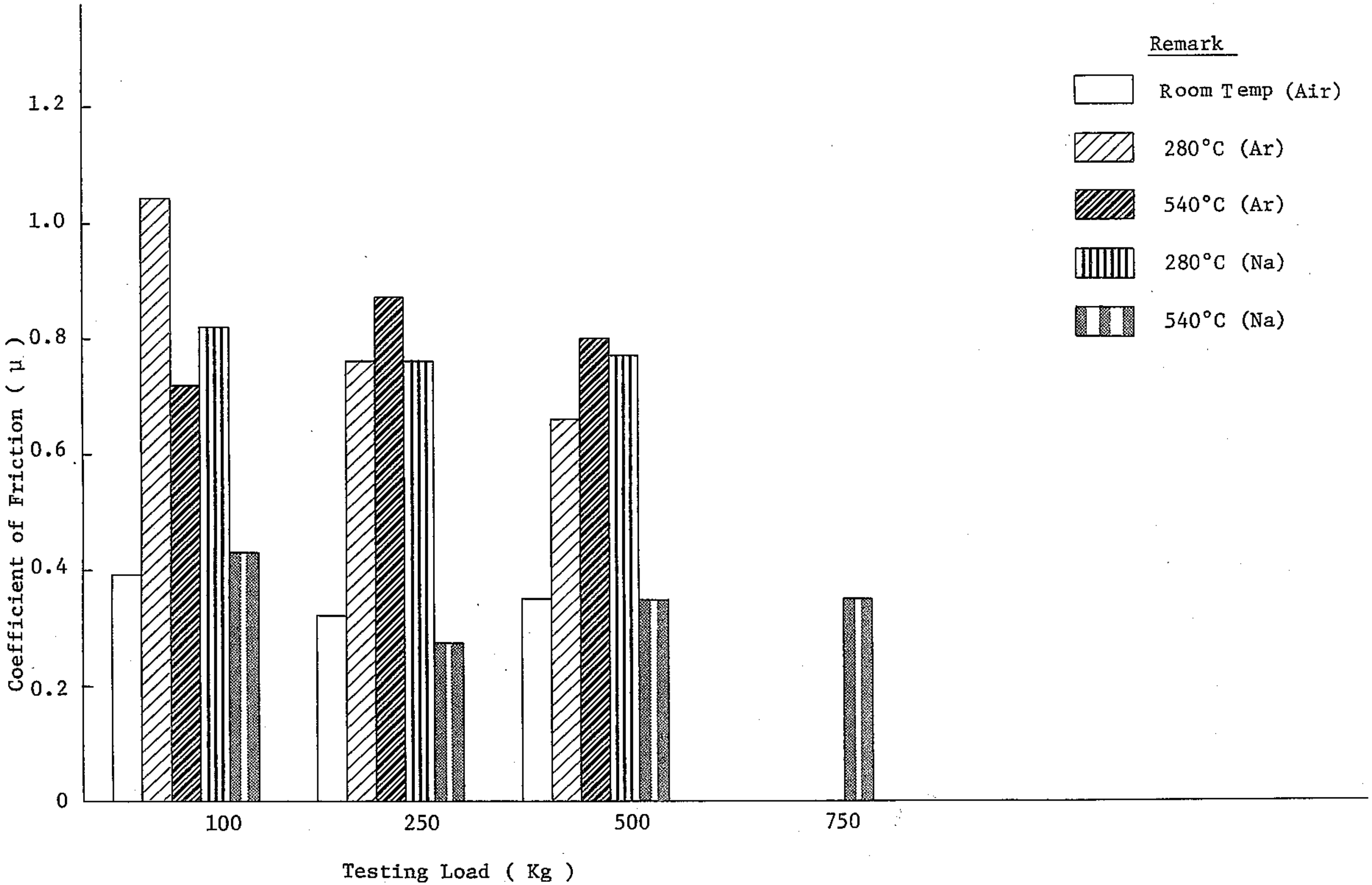



Fig.-18 Changes of Frictional Coefficient on Hard Chrome Plated Material Different Environments

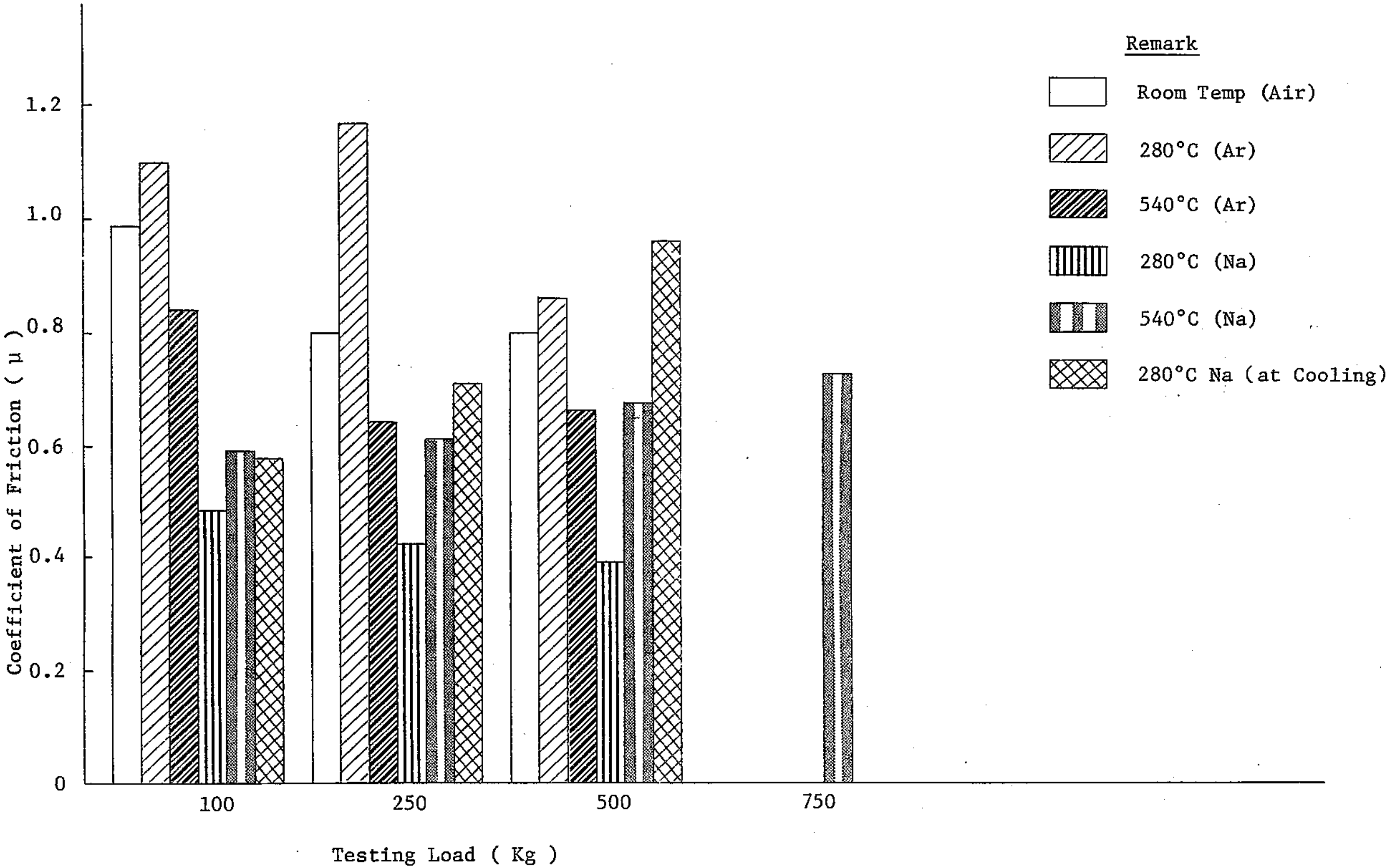



Fig-19 Changes of Fricitional Coefficient on Inconel 718 in the Different Environments

As a preliminary to our projected long term flushing experiment to be undertaken using our SW-3 loop in the future, we have performed a friction test under 500Kg load with about 16-hour flushing to examine the variation of frictional coefficient. As the results, it was found out even such a short sodium flushing had considerably large effects according to the kinds of material. That is, Stellite No. 6, LC-1C, and Hard Cr plated materials deteriorated their behavior by the sodium flushing effect, while Colmonoy No. 6 and Inconel 718 materials showed hardly any visible changes. This experiment was performed under a 500Kg load for the purpose of approximating it to the load applied on the pad section at the time of clamping. In such a test where lubricating emulsion (film) formed on material surfaces poses a problem, the load factor has an important bearing, and therefore, careful consideration must be paid to such phenomena in working on any experiment in the future.

The above description relates to the frictional coefficients of various materials. These calculated coefficient values are those which have been obtained from the torque values at the 60° sliding angle of the first frictional cycle. With such materials which present stable frictional mechanism offer the same values even after repetition of frictional cycle. But some materials show large fluctuation of values. Figs. 21 ~ 25 show the effects of frictional cycles under various conditions. This test was made by repetition movements, and therefore, it may possibly present quite severe conditions than in the case of the same sliding motion. Those which show stable frictional coefficient in these diagrams represent one of the qualifications to be counted as good materials. At room temperatures, carbide materials are stable, and even Hard Cr-plated materials indicate a good behavioral trend under the load up to 500Kg. However, among those candidate materials for padding, such materials as Inconel 718 which is of low hardness show a poor behavioral trend as that of type 316 SS material. The padded materials of Stellite No. 6 and Colmonoy No. 6 show a stable trend despite their high values. These materials when tested in high temperature argon environment, the values become high with carbide materials and Hard Cr-plated materials. In particular, the material of hard chromium plating indicates large fluctuation. Of the in-sodium tested materials, those Hard Cr-plated materials and carbide materials of which surfaces are polished and applied with G.F finish show large changes by the effect of frictional cycle. Here, Fig. 26 show the sum up of frictional coefficients of various materials so far tested under the load of 500 Kg.

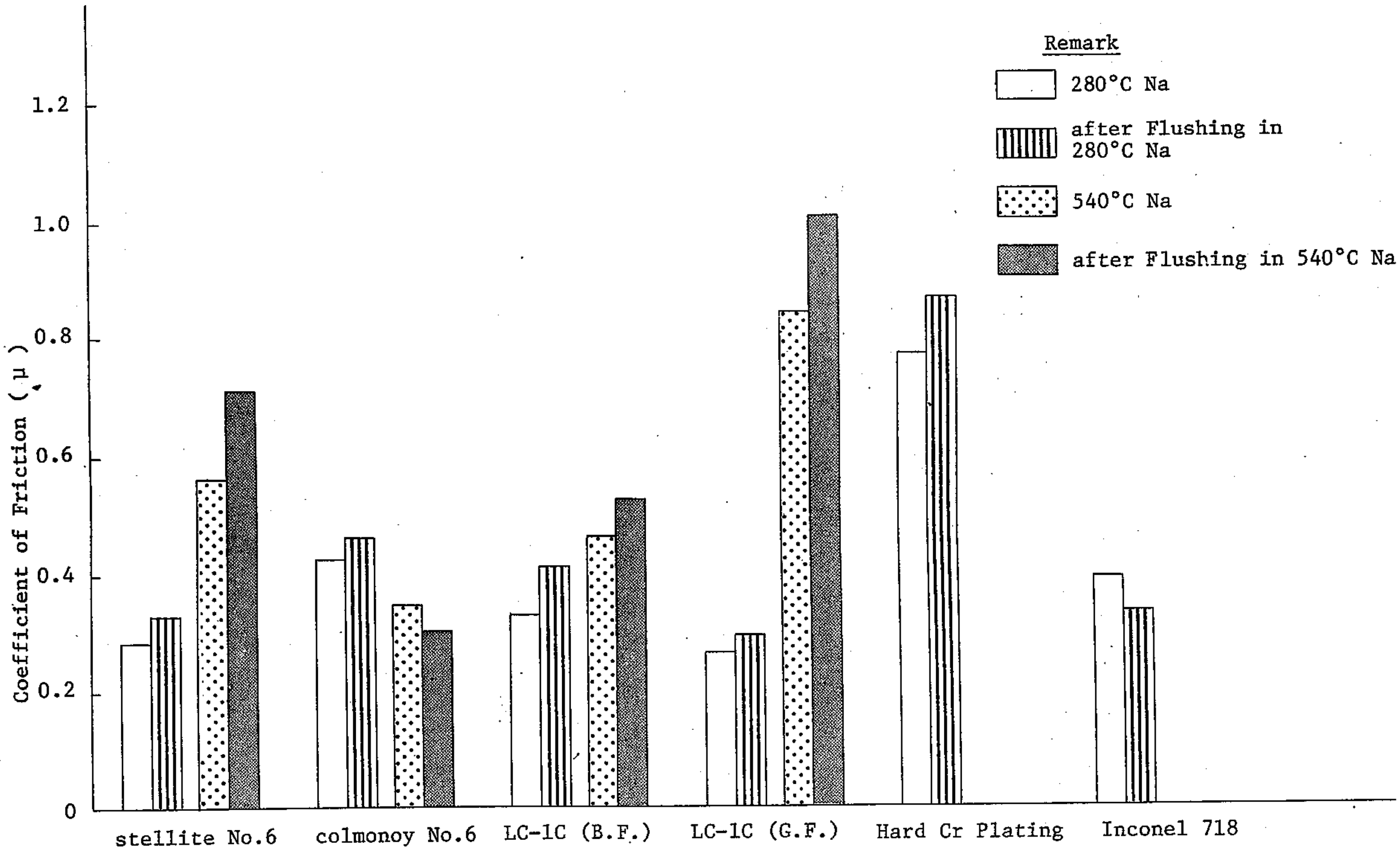
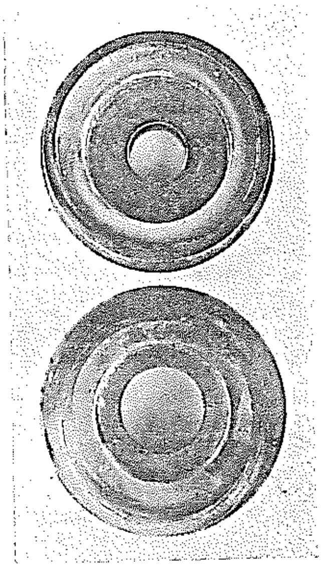
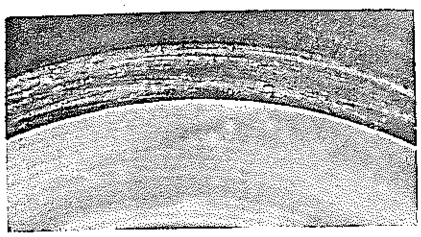
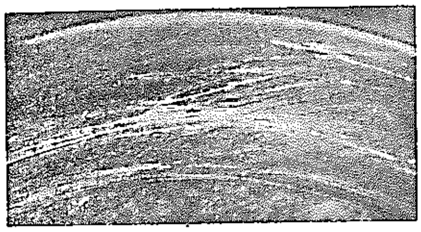



Fig.-20 Sodium Flushing Effect of Various Materials under 500Kg Nominal Load





Rotor Specimen



10mm

2mm

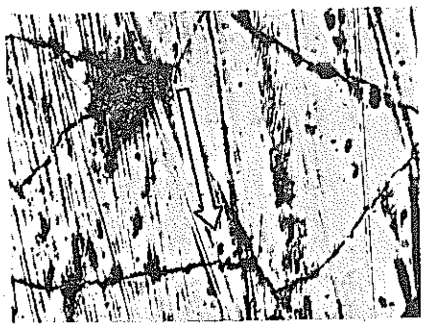
Stator Specimen

External Appearances on the Contacting Surface of Hard Chrome Plating

NON-Frictional Surface

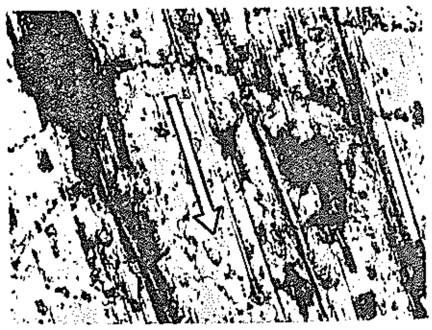
50μ

Frictional Surface



Stator Specimen

50μ

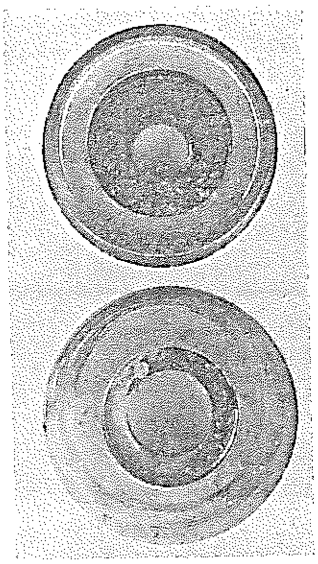


Rator Specimen

50μ

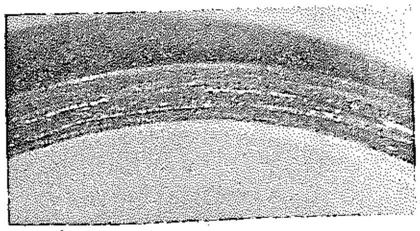
Optical Micrographs on the Surface of Hard Chrome Plating

Photo-13 Results of Metallographic Analysis on Hard Chrome Plated Material in 540 °C Sodium



10mm

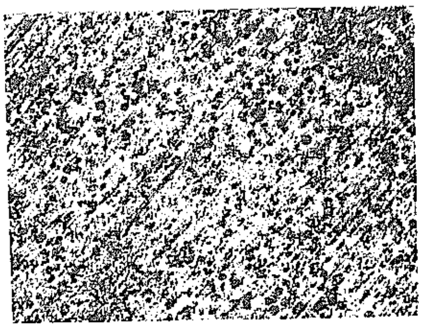
External Appearance of Specimen



Rotor Specimen

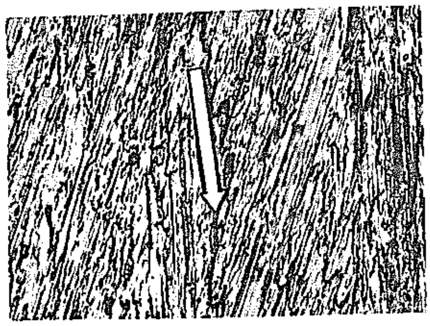
2mm

Stator Specimen



0.1mm

Optical Micrograph on Non-Frictional Surface

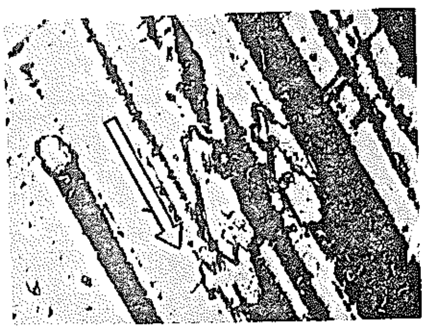


0.1mm

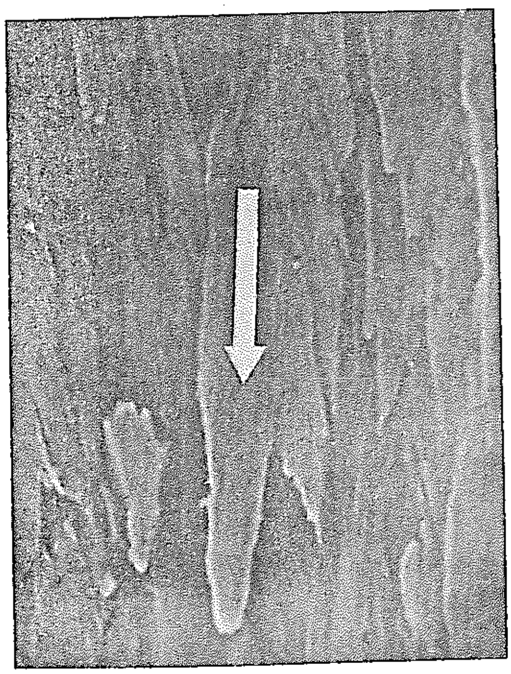
Optical Micrograph on the Frictional Surface

50μ

Non-Frictional Surface →\|← Frictional Surface



10μ



10μ

SEM on the Frictional Surface

Photo-14 Results of Metallographic Analysis on Inconel 718 in 540°C Sodium

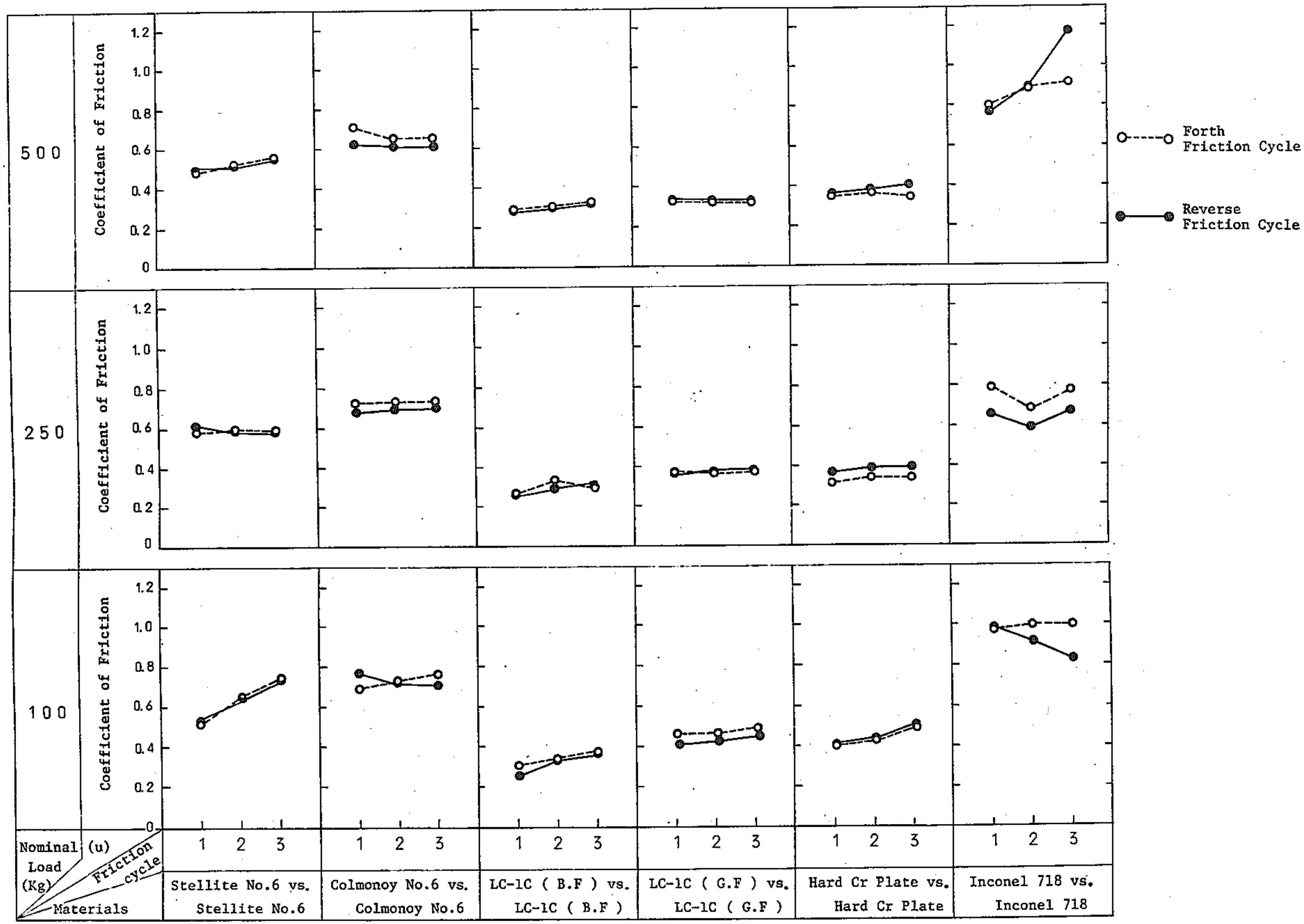



Fig-21 Effect of Friction Cycles on Frictional Coefficient of the Various Material at Room Temp.

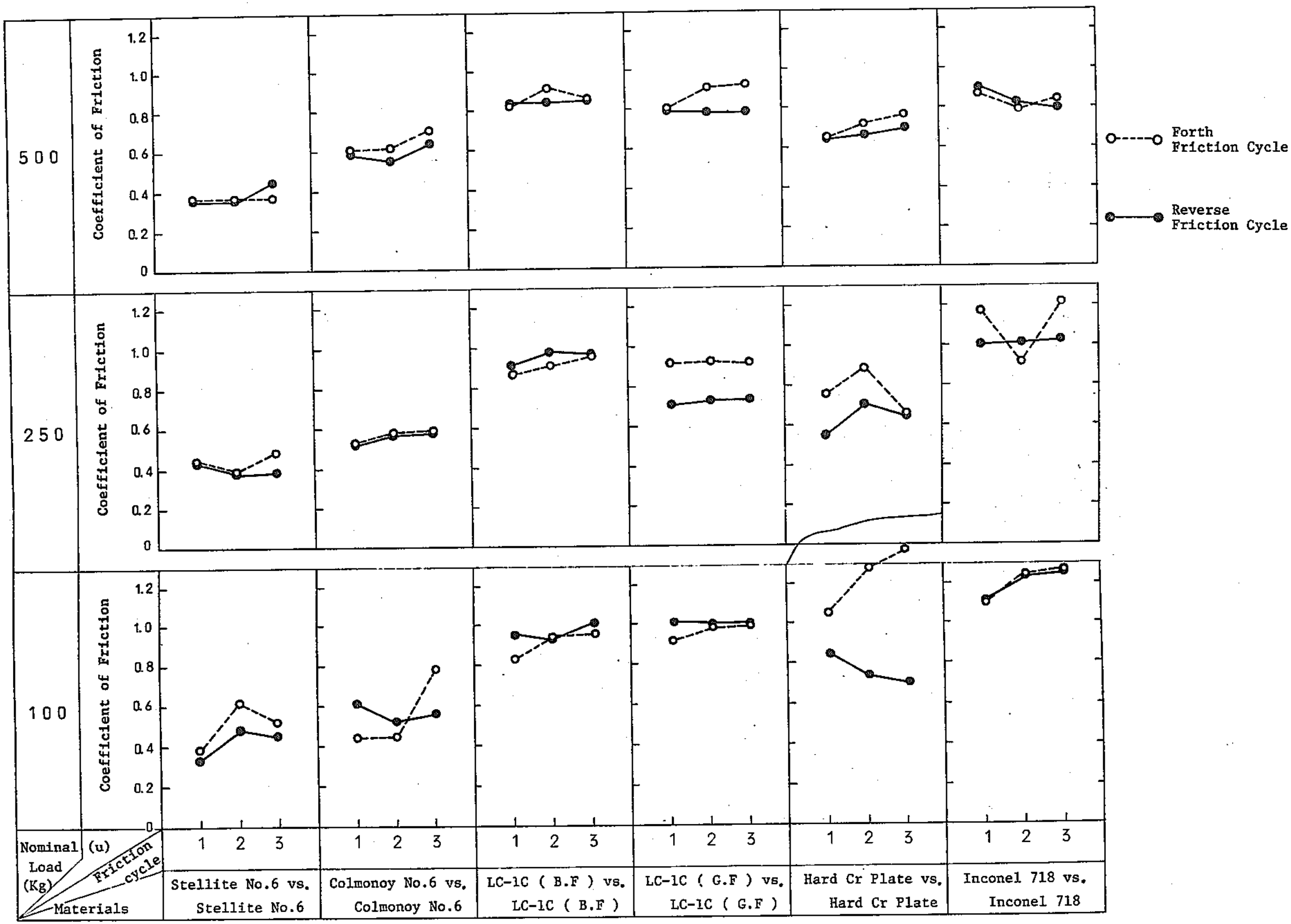



Fig-22 Effect of Friction Cycles on Frictional Coefficient of the Various Materials in 280°C Argon

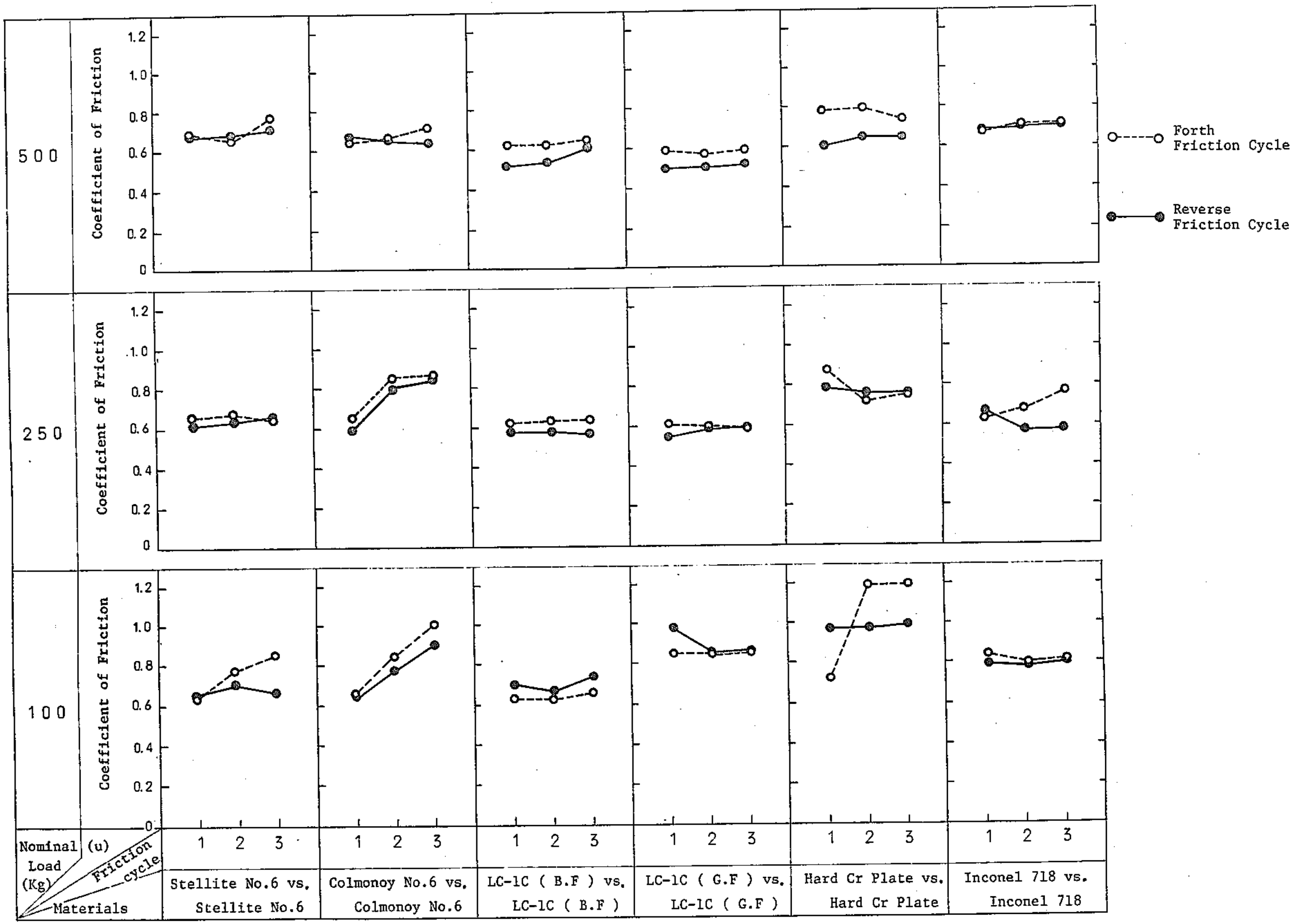



Fig-23 Effect of Friction Cycles on Frictional Coefficient of the Various Materials in 540°C Argon

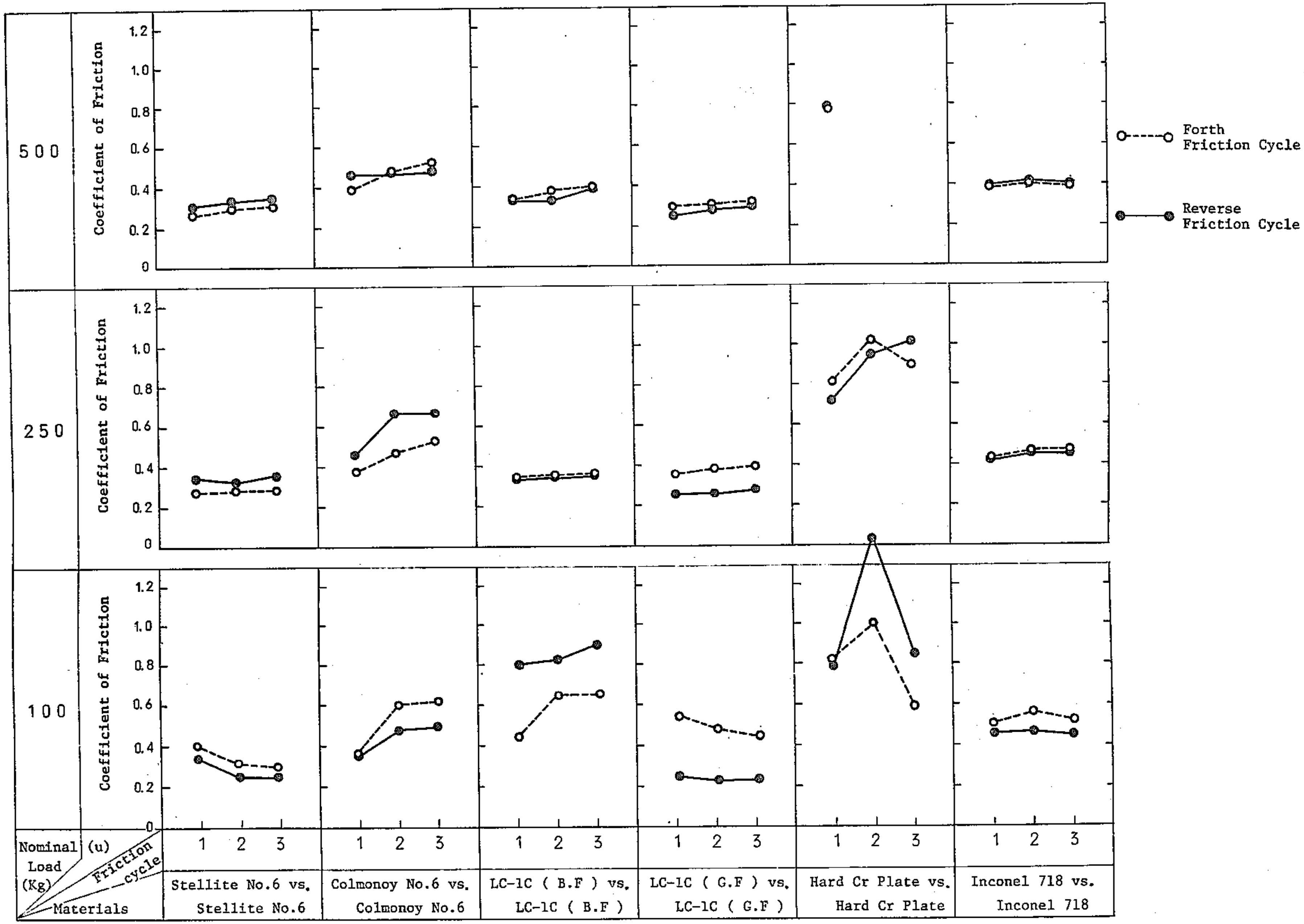



Fig-24 Effect of Friction Cycles on Frictional Coefficient of the various Materials in 280°C Sodium

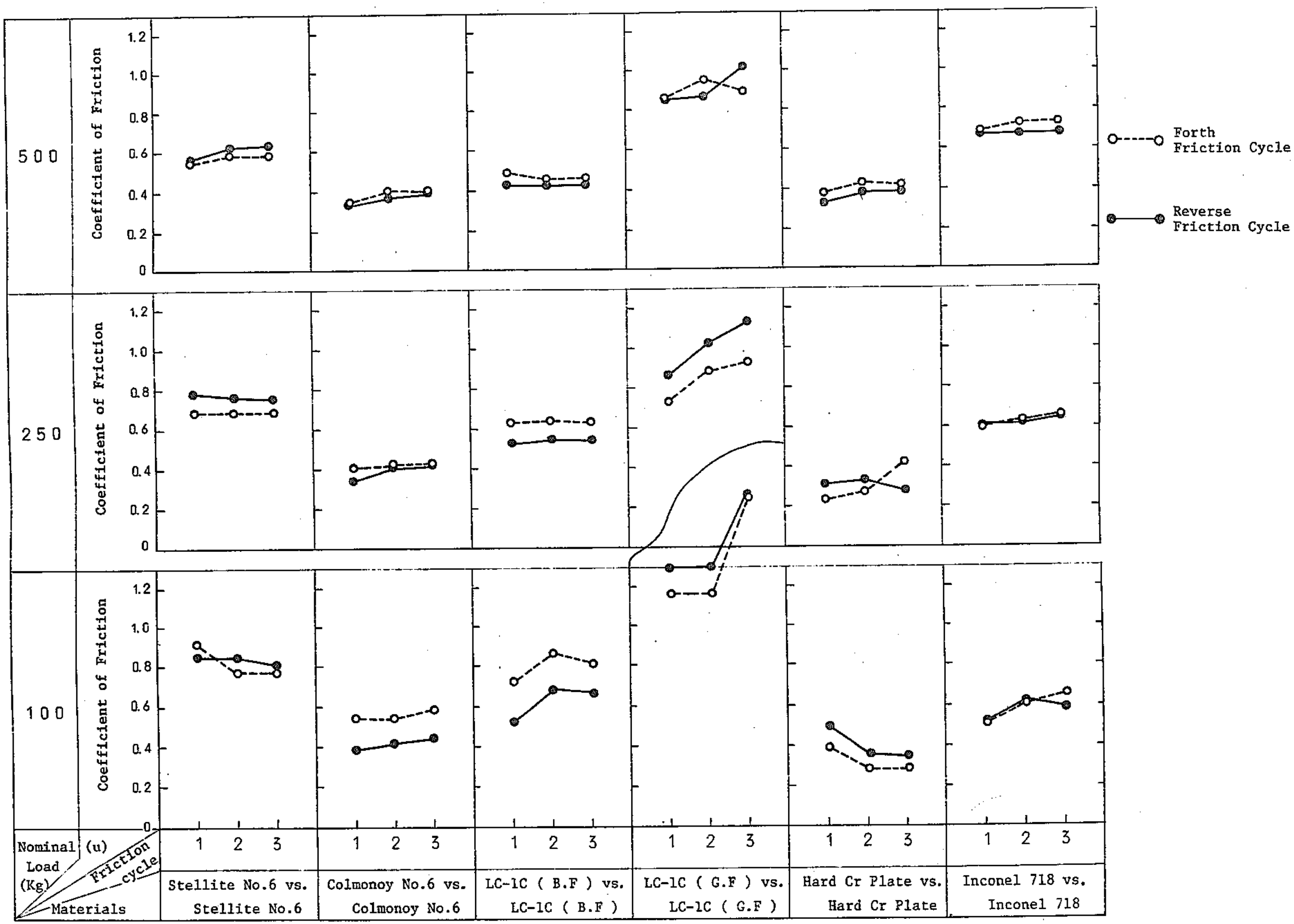



Fig-25 Effect of Friction Cycles on Frictional Coefficient of the Various Materials in 540°C Sodium

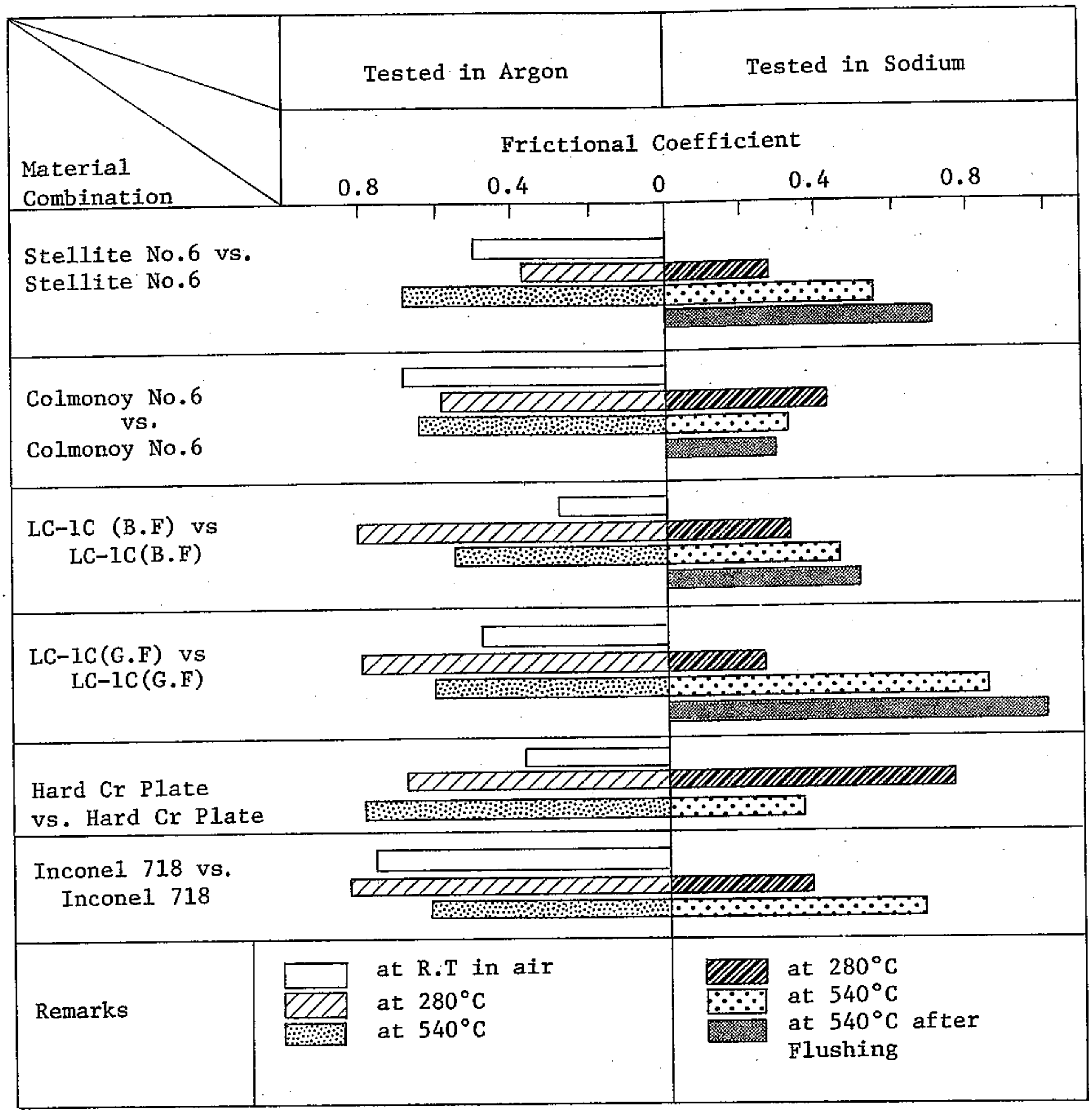



Fig-26 Results of the Friction Test in the different environments under 500Kg Nominal Load

## 3-5 Surface Roughness of Various Materials after Friction Test

It is similarly important for the measurement of frictional coefficient to know the mechanism of surface changes of materials by sliding friction in selecting materials. Particularly, in the case of such materials of reactor components and parts which may possibly be re-employed, it is necessary to evaluate materials from the changes of their surface conditions.

Figs. 27 ~ 37 show the post-test surface roughness of Stellite No. 6, Colmonoy No. 6, LC-1C, Hard Cr-plated and Inconel 718 materials. In the evaluation of these conditions of surface roughness, the final load condition must be taken into consideration. However, of the in-sodium tested materials, Colmonoy No. 6 shows the least surface change. Also, LC-1C material presents the least changed surface roughness which is almost the same as that of its non-contacting area. But that of B.F finish is observed flat and smooth with part of the projected area cut off.

The surface of the Hard Cr-plated material tested in argon shows as much roughness as 100 $\mu$ indicating a complete excoriation of the plated layer, and has exposed the stainless for the mother material, thus the unstable frictional behavior is well endorsed. It is, therefore, estimated that the plated layer suffered a peel-off in the 280 $^{\circ}$C argon environment and under the load condition of 100Kg.

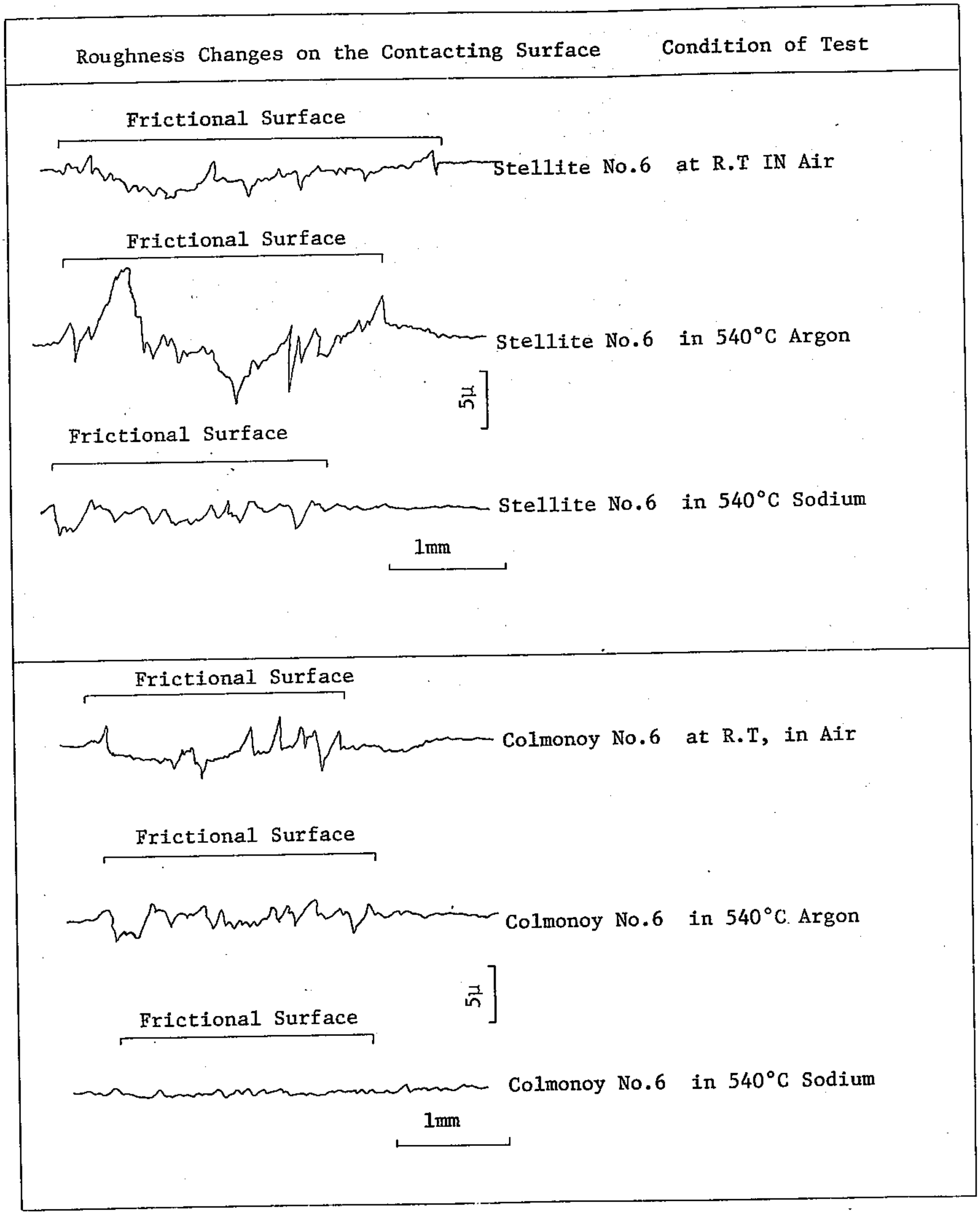



Fig-27 Roughness Changes on the Frictional Surface of Stellite No.6 and Colmonoy No.6 after Tested in the Different Environment

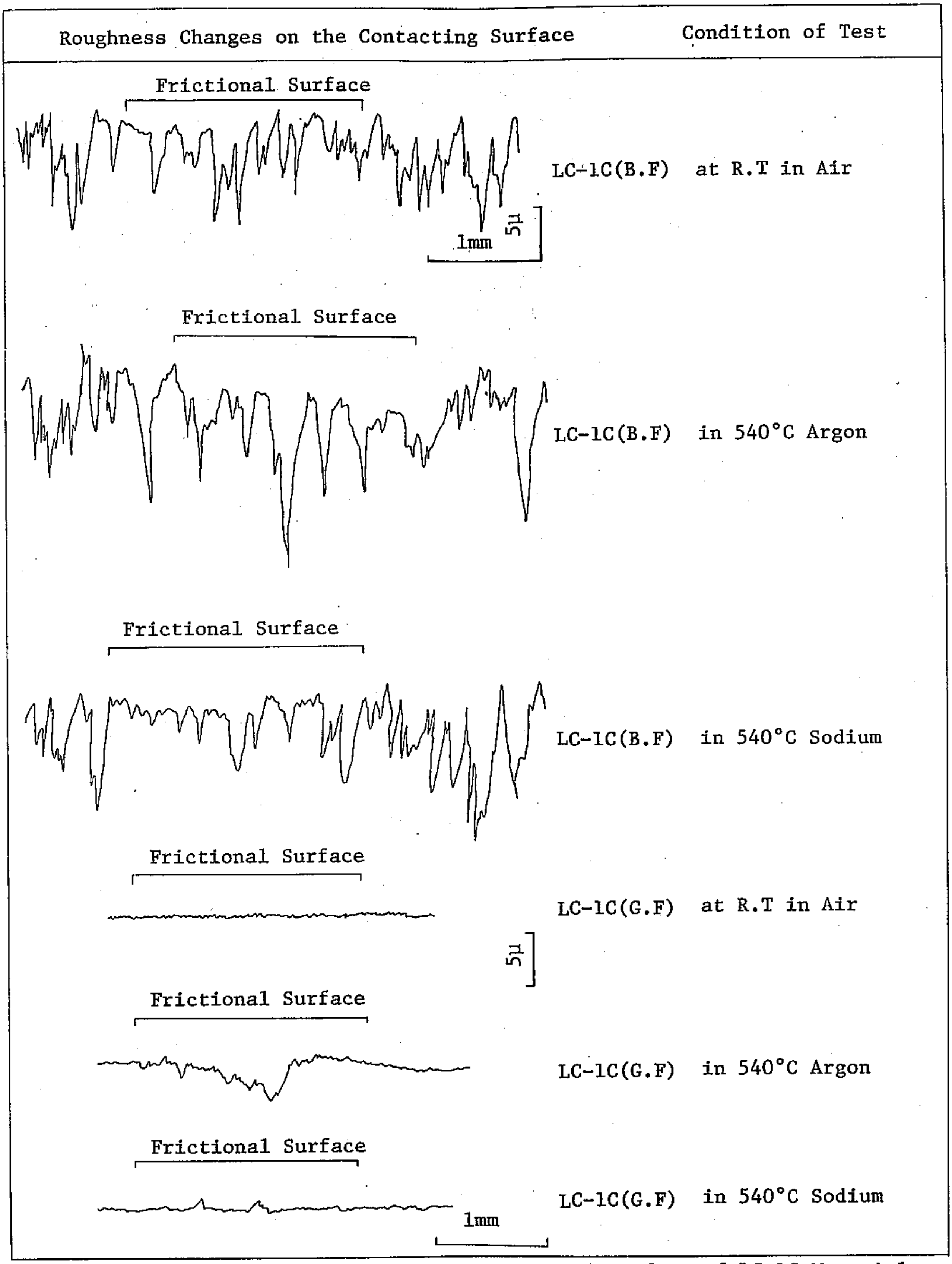



Fig-28 Roughness Changes on the Frictional Surface of LC-1C Material after Tested in the different Environments

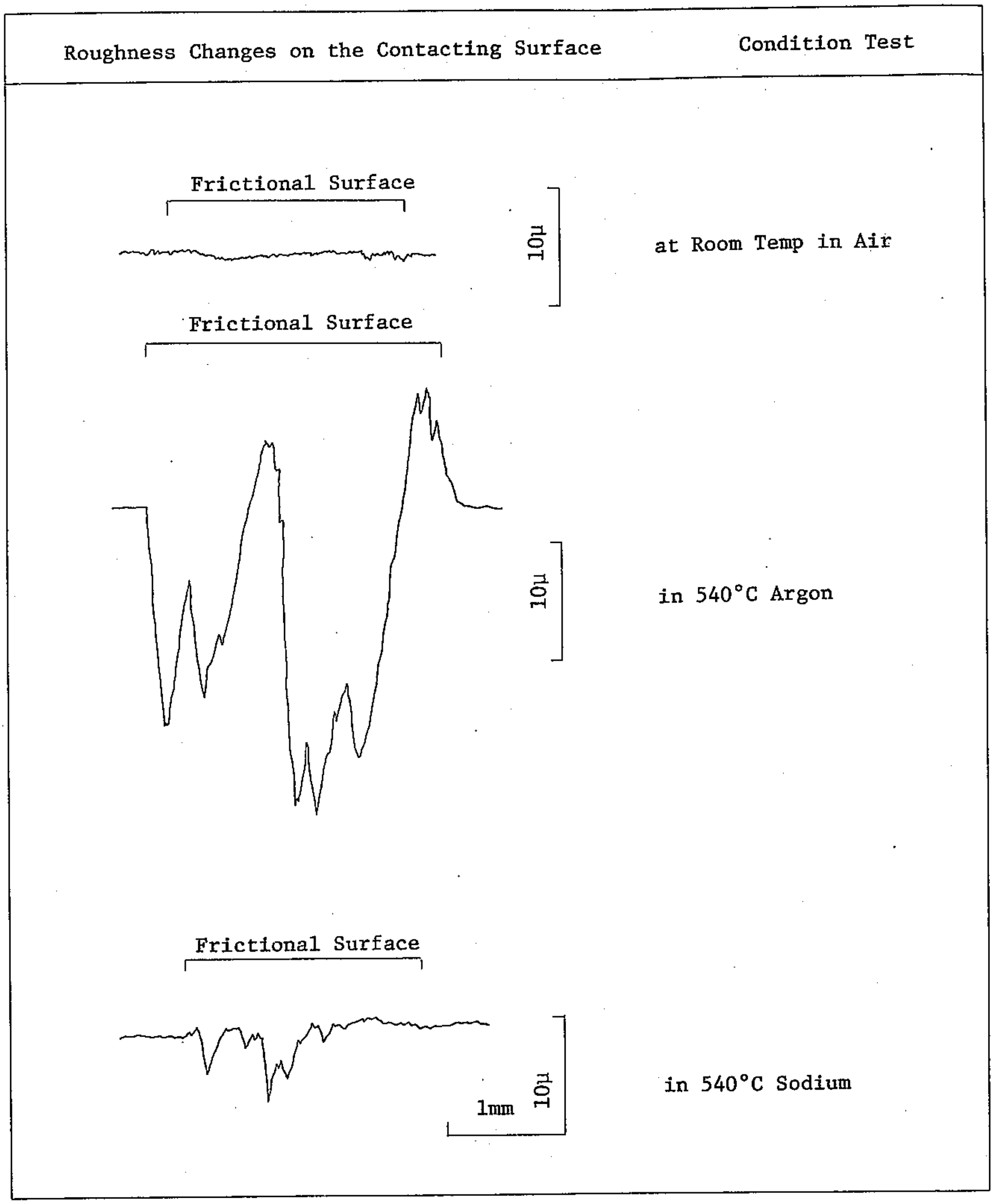



Fig-29 Roughness Changes on the Frictional Surface of Hard Chrome Plating after Tested in the different Environment

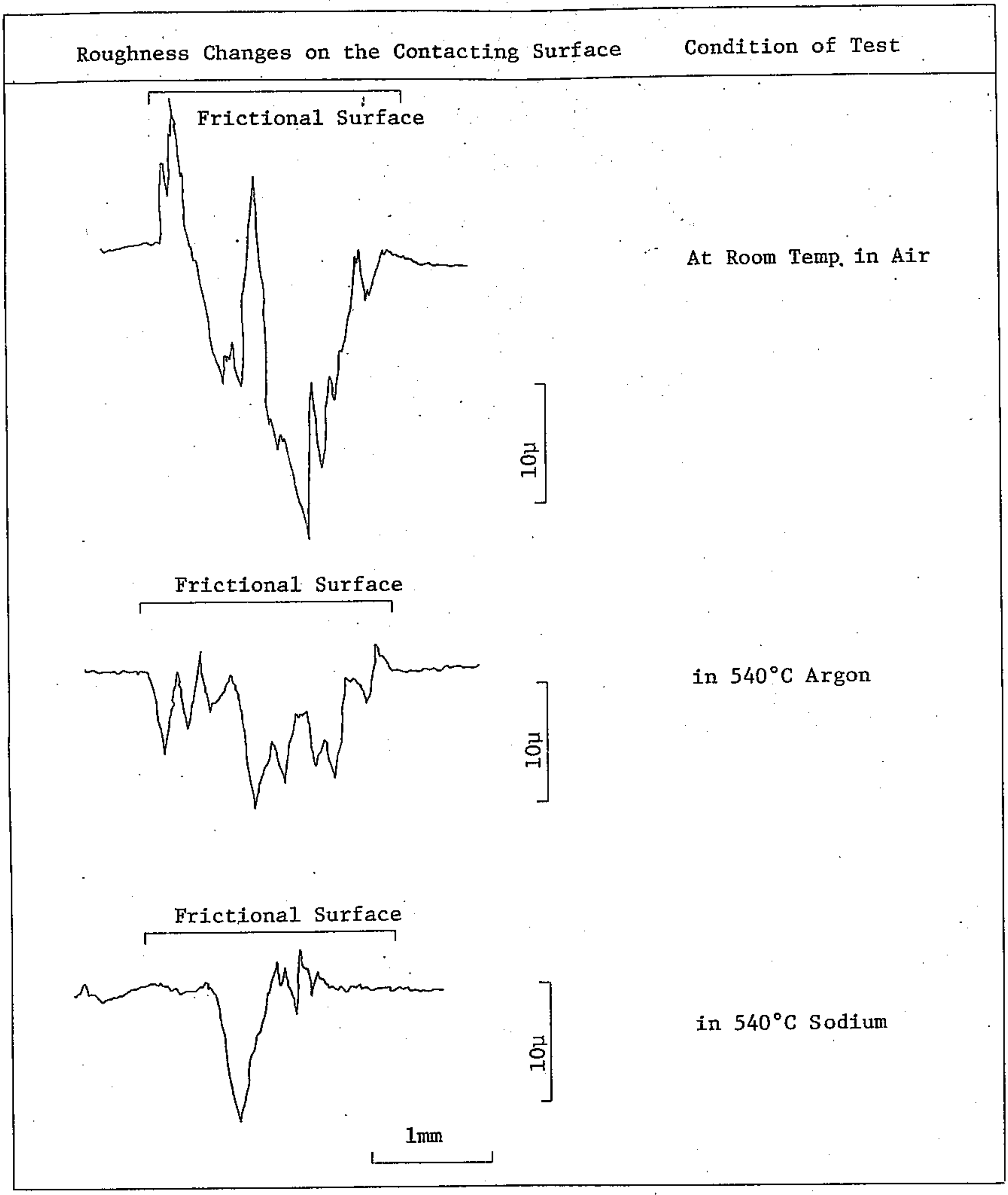



Fig-30 Roughness Changes on the Frictional Surface of Inconel 718 after Tested in different Environment

4. Conclusion

For the selection of materials for FBR fuel assembly padding, 6 kinds of candidate materials were tested under various different conditions for evaluation. The major items as the results of these tests are described as follows:

(1) Though Stellite No. 6 showed stable frictional behavior in 280 °C sodium, and also the effect of sodium flushing was large.

(2) Colmonoy No. 6 showed stable frictional coefficient in the range of 0.3 ~ 0.4 under a heavy load of 500Kg even after sodium temperature rose.

(3) Chromium carbide material showed different trends of behavior according to surface finished conditions. In particular, in high temperature sodium, those with polished surface showed frictional coefficient abov 1.0, and likewise the effect of sodium flushing was great.

(4) The material with Hard Cr-plating showed unsatisfactory frictional behavior indicating high frictional coefficient of 0.8 even in 280 °C sodium.

(5) Inconel 718 materials, which showed relatively high frictional coefficient of 0.6 ~ 0.7 in sodium indicated stable frictional behavior.

(6) The frictional coefficient in inert gas showed generally higher values comparing with those in sodium. But according to test conditions, some materials indicated inferior behavior than in the case of sodium.

It has been proved that Colmonoy No. 6 and carbide material's LC-1C (B.F) are the prospective materials for fuel assembly padding under the sodium environment condition upto 540 °C.

The next series of self-welding experiments evaluation of self-welding behavior from the increase of torque values after applying load and holding it for a given length of time on these combinations of materials, and also for the evaluation of self-welding mechanism under accelerated self-welding on various combinations of materials with type 316 SS as their partner. The results of these evaluations shall be described in the subsequent report.

Upon finalizing this report, may we add that production of this report was greatly facilitated by the generous cooperation of many people. In particular, we wish to thank Messrs. Umehara and Yamamoto of JOYO Sangyo for their assistance and advice.

## 5. Referential Literature

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(3) Mizobuchi, and Kanoh, et al.: "Self-Welding Test in High Temperature Sodium"

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