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CREEP RECOVERY AND STRESS RELAXATION TESTS OF 6061-O ALUMINUM

by

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ABSTRACT

In an earlier report, it was shown possible to conduct creep tests by use of a closed loop servo-hydraulic test system. These tests were different from the conventional creep tests in that the strain history prior to creep could be carefully monitored. In this investigation, creep recovery and stress relaxation have been studied using the same approach.

CHAPTER I

INTRODUCTION

In an earlier report [1], it was shown possible to conduct creep tests by use of a closed loop servo-hydraulic test system. These tests were different from the conventional creep tests in that the strain history prior to creep could be carefully monitored. The tests were controlled by a PDP 11/04 minicomputer at a preset constant plastic-strain rate prehistory. The test system and the analog and digital hardware and software were explained in Ref. [1].

Among the observations of this investigation are the following:

1. Constant plastic-strain-rate tension tests are practical using a computer controlled test system.
2. The plastic-strain-rate prior to creep has a noticeable effect on creep behavior of aluminum.
3. The magnitude of the intial plastic strain has a noticeable effect on the subsequent creep behavior.

The purpose of the present investigation is to extend the approach of Ref. [1] to the study of creep recovery and stress relaxation.

CHAPTER II

EXPERIMENTS

Material and Specimens

An Aluminum alloy 6061-T6 was tested in these experiments. Specimens were machined from 2.54cm×0.476cm rectangular bars as used in Ref. [1]. The thickness, width, and gage length of the specimens are 0.476, 0.795 and 3.81cm respectively. Figure 1 shows the geometry of the specimens.

Since the materials was T6 temper as received, all specimens were heat treated after machining. They were wrapped in aluminum foils and annealed at 343^{0}C for 150 minutes. The exprimental stress-strain curves show that the specimens were almost fully annealed after heat treatment.

Apparatus

The tests were conducted on a closed loop, hydraulic driven, servocontrolled test system (MTS system). This system, as described in Ref. [1], was operated as a standard closed loop system but derived its command signal from a PDP 11/04 minicomputer.

For all experiments, the strain signal was measured by an INSTRON clip gage extensometer mounted on the specimen

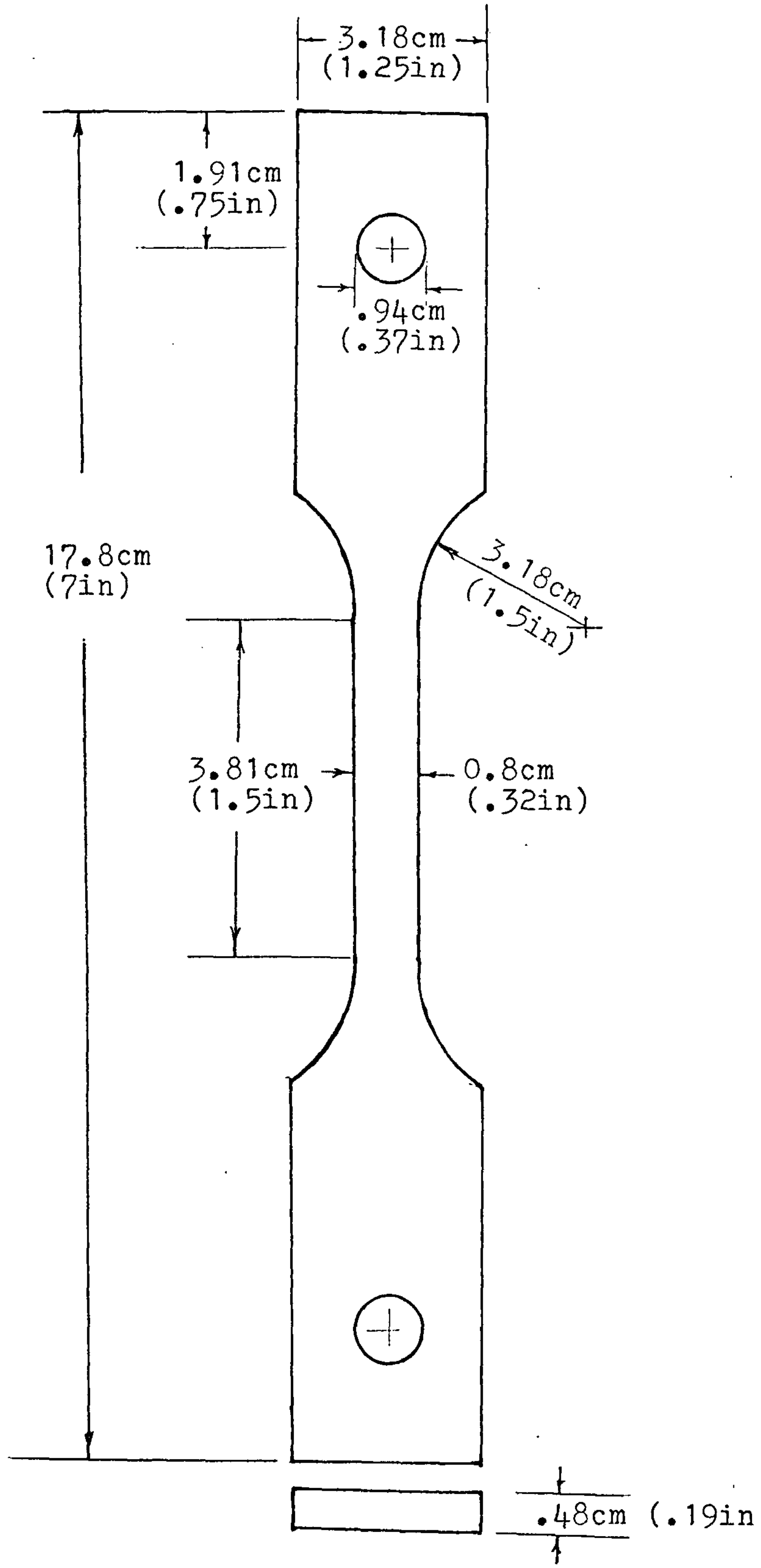

Figure 1: Specimen Geometry

gage section and a stress signal was measured by a MTS built-in load-cell. During testing, these two signals were recorded continuously and stored in a floppy diskette. Then the data was send to the PRIME 750 facility at the university's computer center for further investigation.

Experimental program

The experimental programs for creep recovery and stress relaxation tests are summarized in Tables 1 and 2 respectively. All specimens were tested at 150°C in an environmental chamber. In order to observe the influence of plastic-strain-rate all tests were conducted with a constant plastic-strain-rate preloading. This was done by using the minicomputer to control the loading history. Considering the system capabilities and the material properties, three plastic-strain rates (10^{-3}, 10^{-4} and 10^{-5}) were chosen for this investigation.

The creep recovery tests had two creep stages. The specimens were initially loaded to the first stage with a constant plastic-strain-rate pre-history. The stress was then kept constant for the first creep stage. After 90 minutes of creep, the specimen were unloaded to a lower stress level for creep recovery, which also lasted for 90 minutes. Some specimens had a third stage of creep, i.e. specimens CB4 and CB5. During this third stage, the stress

Table 1

Creep Recovery Test Program

Specimen Number	Prehistory Strain-rate (s^{-1})	Stress Magnitude 1st stage	(MPa) 2nd stage	3rd stage	Specimen Area (cm^2)
CA1	10^{-3}	89.6	82.7	*	0.4056
CA2	10^{-3}	75.8	68.9	*	0.4162
CB1	10^{-4}	89.6	82.7	*	0.4085
CB2	10^{-4}	75.8	68.9	*	0.4006
CB3	10^{-4}	82.7	62.0	*	0.4053
CB4	10^{-4}	82.7	75.8	82.7	0.3957
CB5	10^{-4}	75.8	68.9	75.8	0.4001
CC1	10^{-5}	89.6	82.7	*	0.4009
CC2	10^{-5}	75.8	68.9	*	0.3918

Table 2

Stress Relaxation Test Program

Specimen Number	Prehistory Strain-rate (s^{-1})	Strain Magnitude 1st stage (%)	Strain Magnitude 2nd stage (%)	Specimen Area (cm^2)
RA1	10^{-3}	0.5	2.0	0.3944
RA2	10^{-3}	1.0	*	0.4023
RA3	10^{-3}	1.5	*	0.4031
RB1	10^{-4}	0.5	2.0	0.3963
RB2	10^{-4}	1.0	2.0	0.3996

was increased back up to the magnitude of the first stage for further investigation of the creep recovery phenomenon.

In the relaxation tests, all specimen were also loaded according to constant plastic-strain-rate loading history. After a prescribed strain level had been reached, the strain was kept at this level in order to observe the stress relaxation phenomenon. The period for each relaxation test was 30 mimutes. Some specimens had a second stress relaxation stage. In this case, the specimens were loaded back up, after the first relaxation stage, to a higher strain level for a second stage relaxation test.

CHAPTER III

TEST RESULTS

Experimental results of creep recovery are shown in Figures 2-7. Shown in Figures 8-10 are the stress relaxation test results. From these figures, it is seen that the plastic-strain-rate of the loading stage may have a significant effect on the behavior of creep recovery and stress relaxation depending on the test condition.

Creep Recovery

The stress-strain curves of three constant strain-rates are shown in Figure 2, which shows that the plastic-strain-rate has pronounced effect on the stress-strain curves. However, the strain-rate sensitivity may not be proportional to the strain-rate as discussed by Wu and Yao in [1]. For Aluminum 6061-O alloy, the strain-rate sensitivity is greater in the strain-rate range of 10^{-4}-10^{-5} S^{-1} than in the range of 10^{-3}-10^{-4} S^{-1}.

Figure 3 shows the creep recovery curves of stress 68.9 MPa unloaded from 75.8 MPa. For the case of low creep stress level as in Fig. 3, the accumulated recovery strain is very small, and hence the preloading strain-rate does not

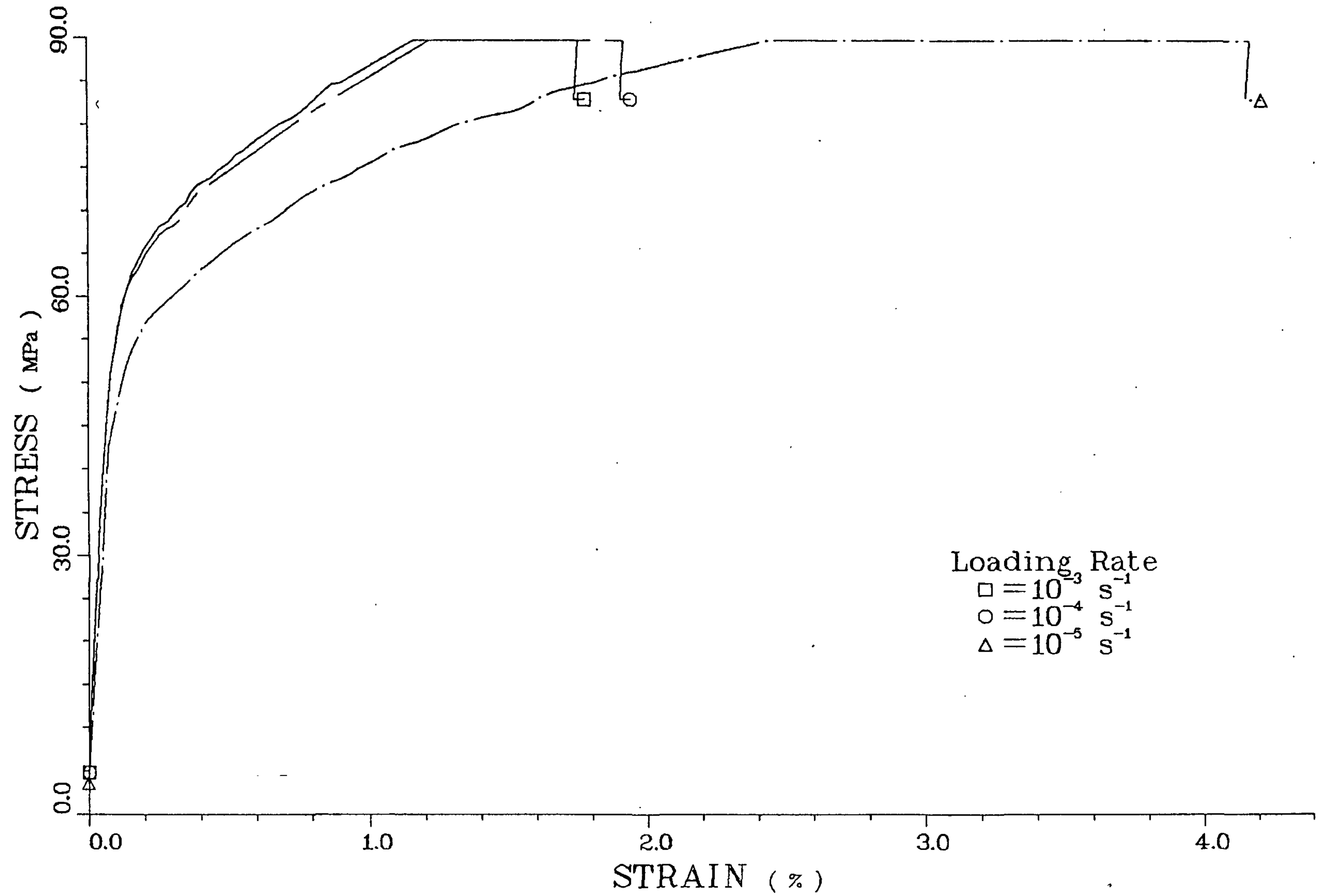

Fig 2: Stress–Strain Curves

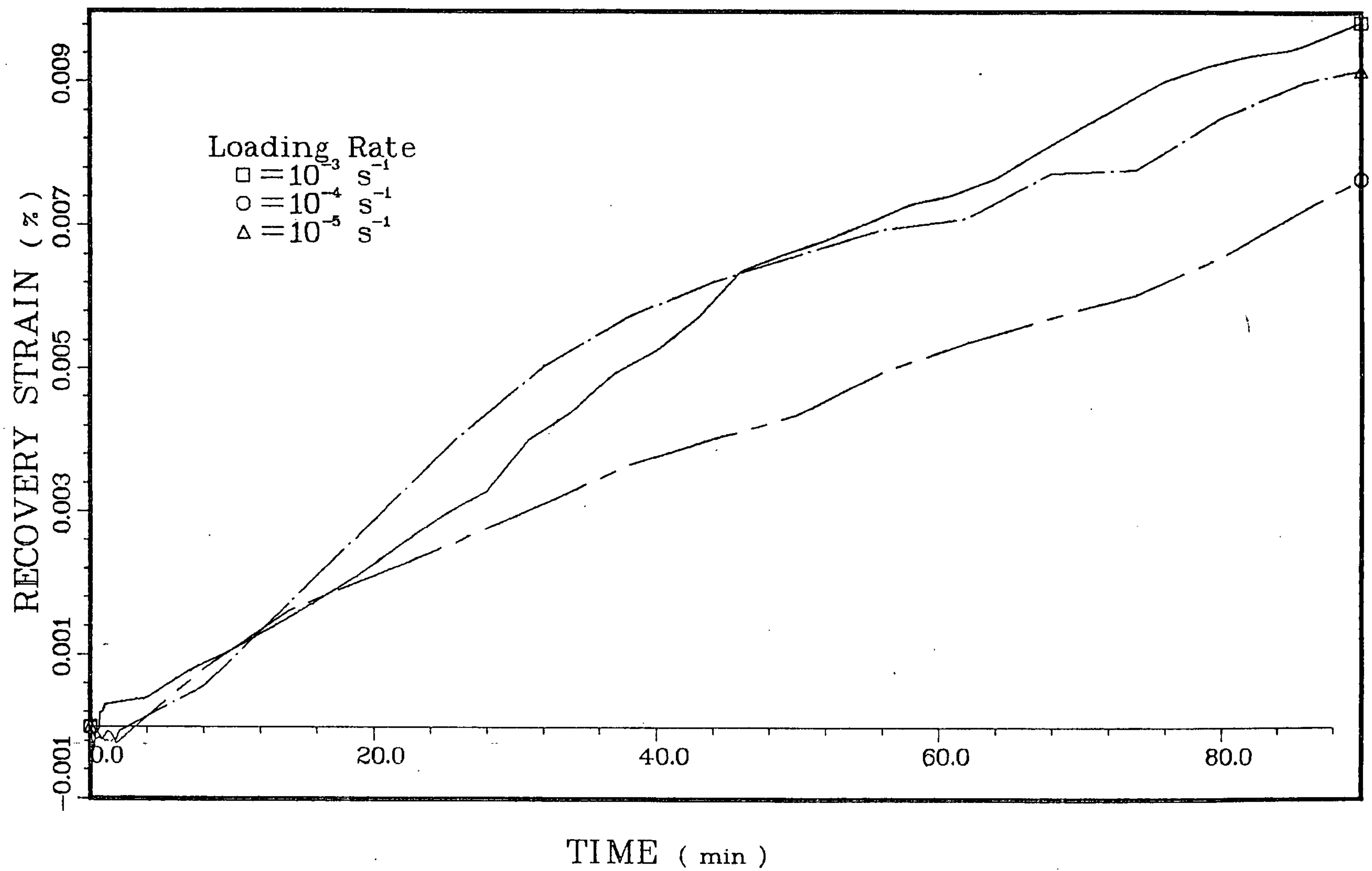

Fig 3: Creep Recovery Curves at 68.9 MPa

have an appreciable effect on these curves. Shown in Figure 4 are the creep recovery curves obtained by reducing the stress from 89.6 MPa to 82.7 MPa. At this high creep stress level, the preloading strain rate has a significant effect on the magnitude of the initial strain, which in turn affects the subsequent creep behavior. It should be noted that specimen CC1 has higher forward creep stains than the other specimens which were tested at higher preloading strain rates. One explanation is, as in the creep experiments explained by Wu and Yao [1], that although the specimen with lower loading strain-rate prehistory has a lower initial creep rate, the accumulated creep strain is larger since it has an higher initial plastic strain.

Now, creep recovery curves of same loading strain-rate at different stress levels are compared in Figure 5. The recovery curves of specimens CB1, CB4 and CB5 (coincide with CB2) show that forward creep occurs when the drop in stress is small. Moreover, although these three specimens have experienced the same amount of stress reduction (6.9MPa), the specimen higher stress magnitude produces larger forward creep strain. Also, comparing the results of CB4 and CB3, which were obtained by unloading from the same stress level (82.7MPa) but with different stresses in the second stage, CB4 shows a forward creep but CB3 shows a natural strain recovery due to a larger drop in stress.

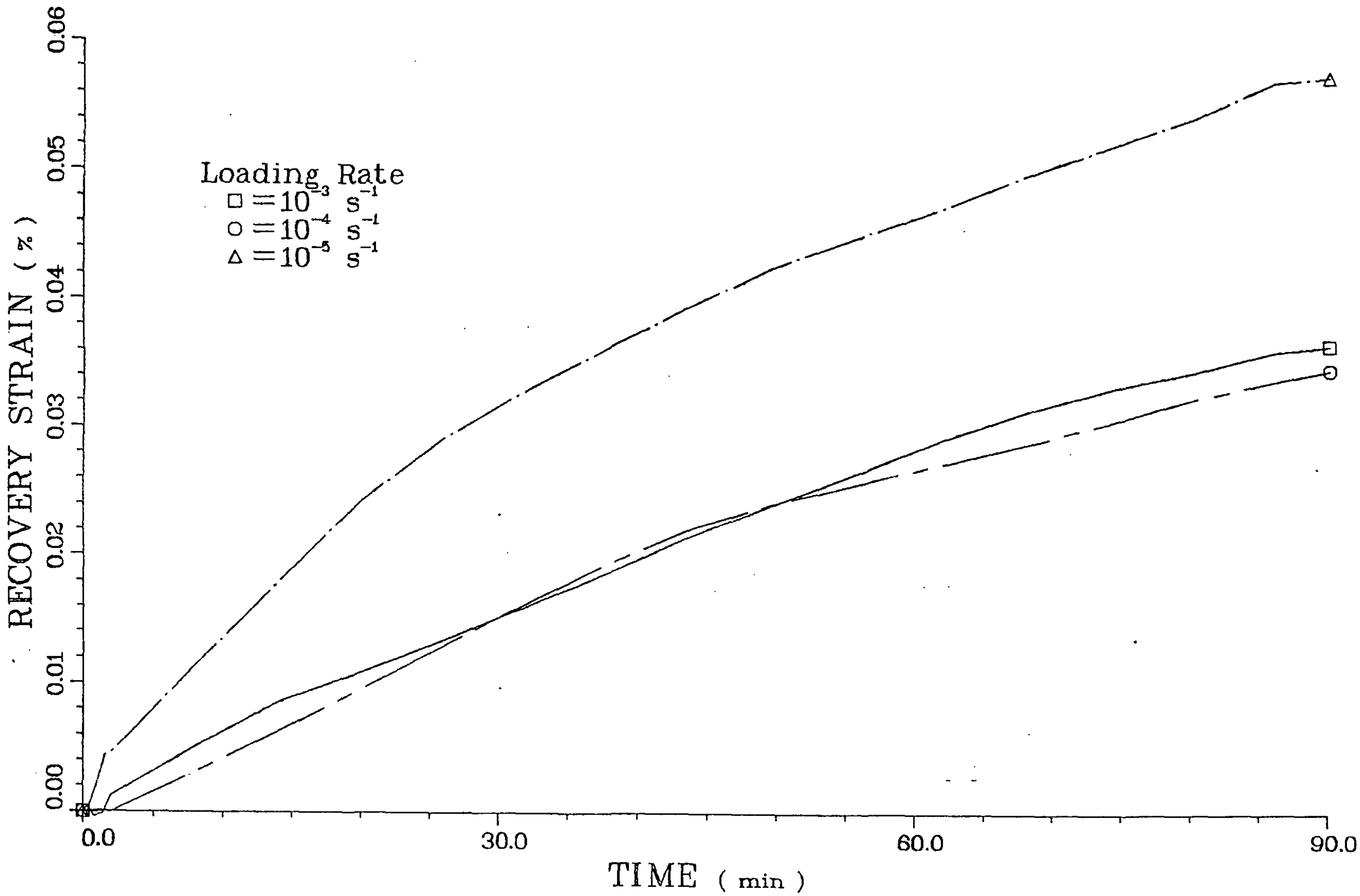

Fig 4: Creep Recovery Curves at 82.7 MPa

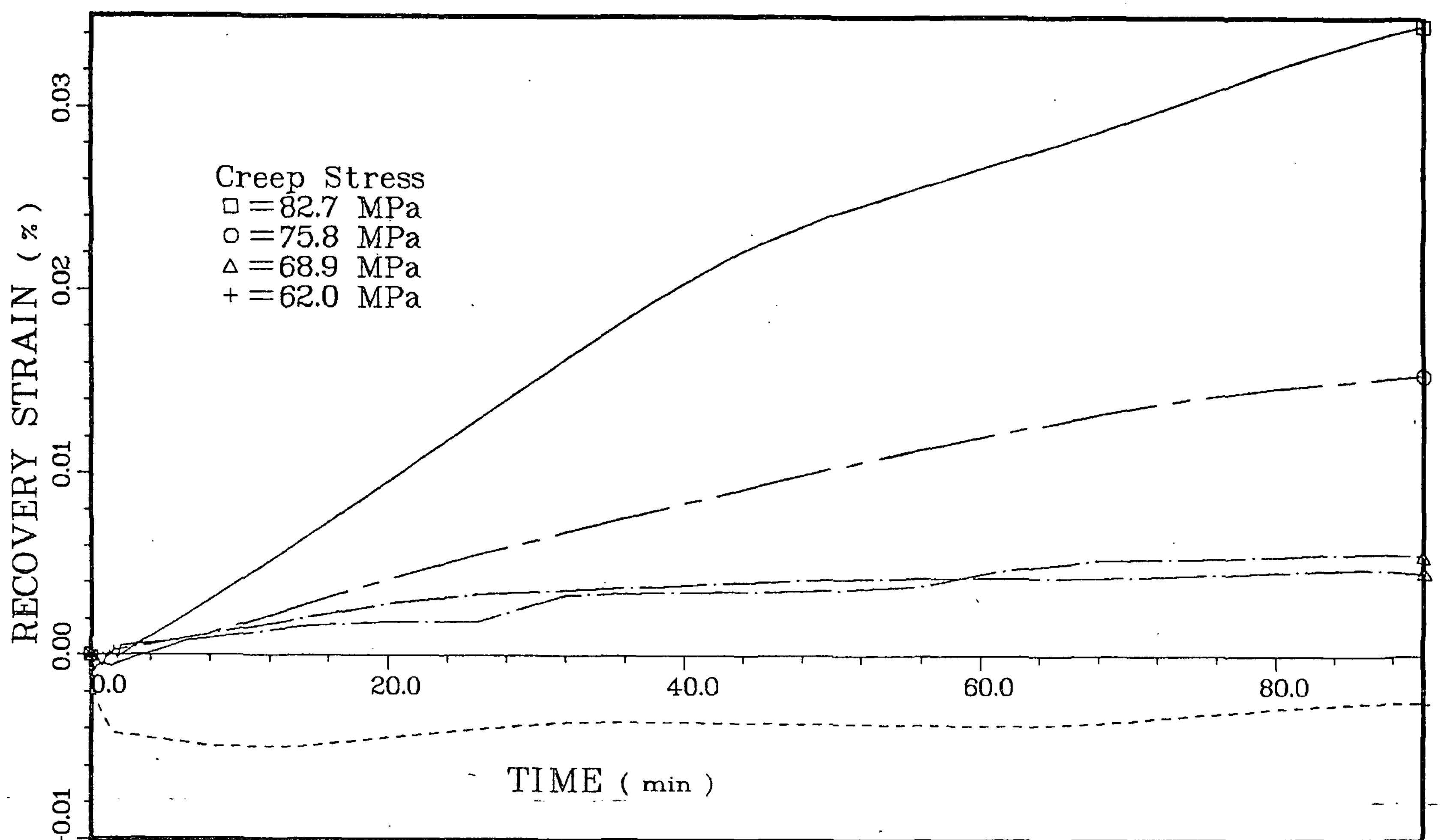

Fig 5: Creep Recovery Curves

Loading Strain Rate 10^{-4} s^{-1}

Figures 6 and 7 show the first and third stage creep curves of specimens CB4 (82.7MPa) and CB5 (75.8MPa). From these two figures, it was observed that the third stage creep curves are almost straight lines without a transient part.. Also, the creep rates seem to be the continuation of the first stage.

Relaxation Curves

The stress relaxation curves for different strain level are shown in Figure 8. These were all tested with a preloading strain-rate of 10^{-3} s^{-1}. It is seen that strain magnitude has a significant effect on the behavior of stress relaxation. The higher the strain magnitude is, the larger is the stress in relaxation.

Figure 9 and 10 demonstrate the effect of strain-rate in preloading on the behavior of stress relaxation. Although the prehistory strain-rate are different, the stress relaxation curves of 1.0% strain level shown in Figure 9 almost coincide. On the contrary, in Figure 10, the relaxation curve of RA1 (loading strain rate = 10^{-3} s^{01}, strain level= 2.0%) is different than that of RB1 and RB2 (loading strain rate = 10^{-4} s^{-1}, strain level = 2.0%). RA1 with higher initial stress relaxed more.

It should also be remarked that although preceded by different strain-histories, i.e. RB1 had a first stage

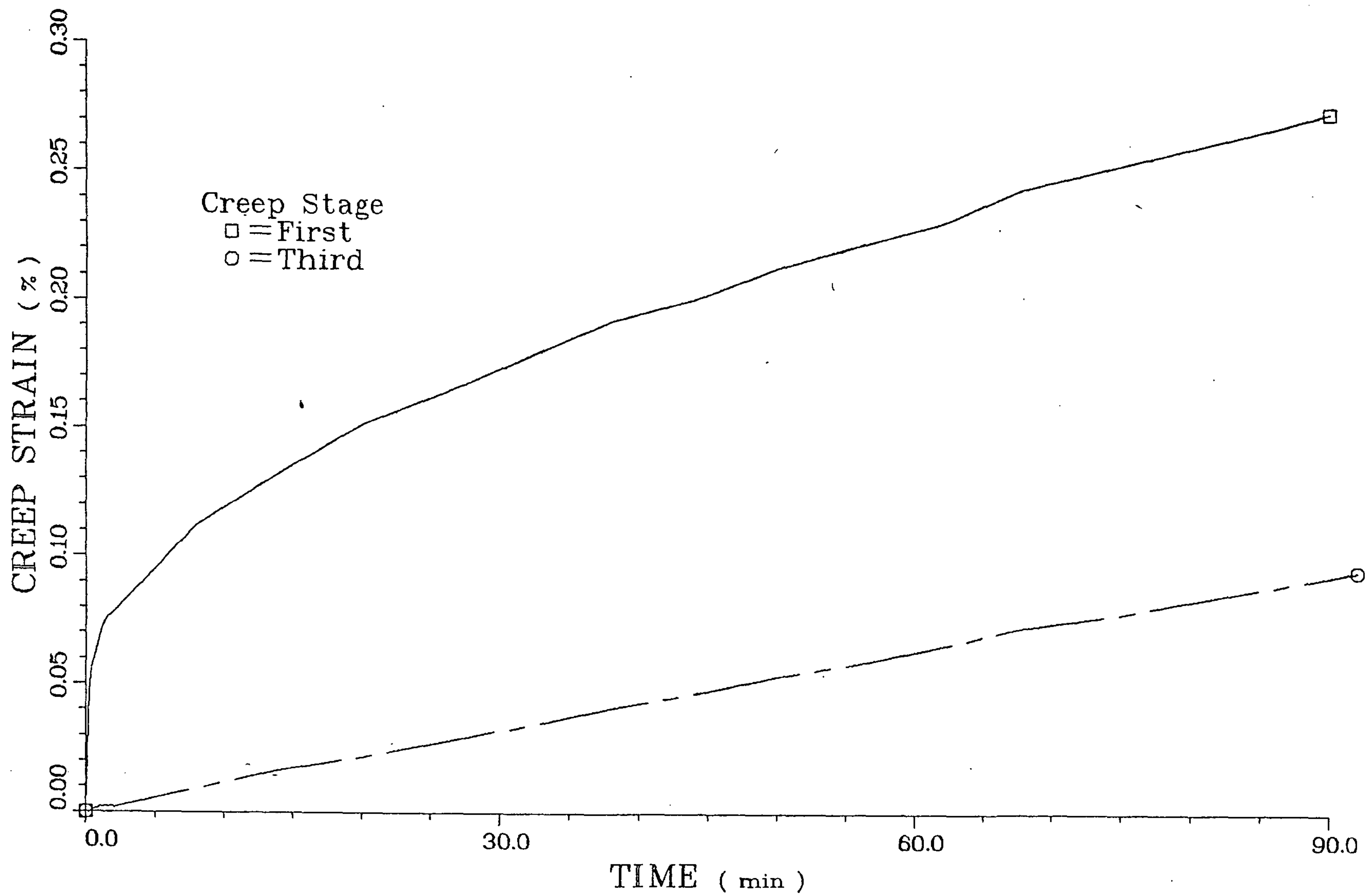

Fig 6: Creep Recovery Curves at 82.7MPa

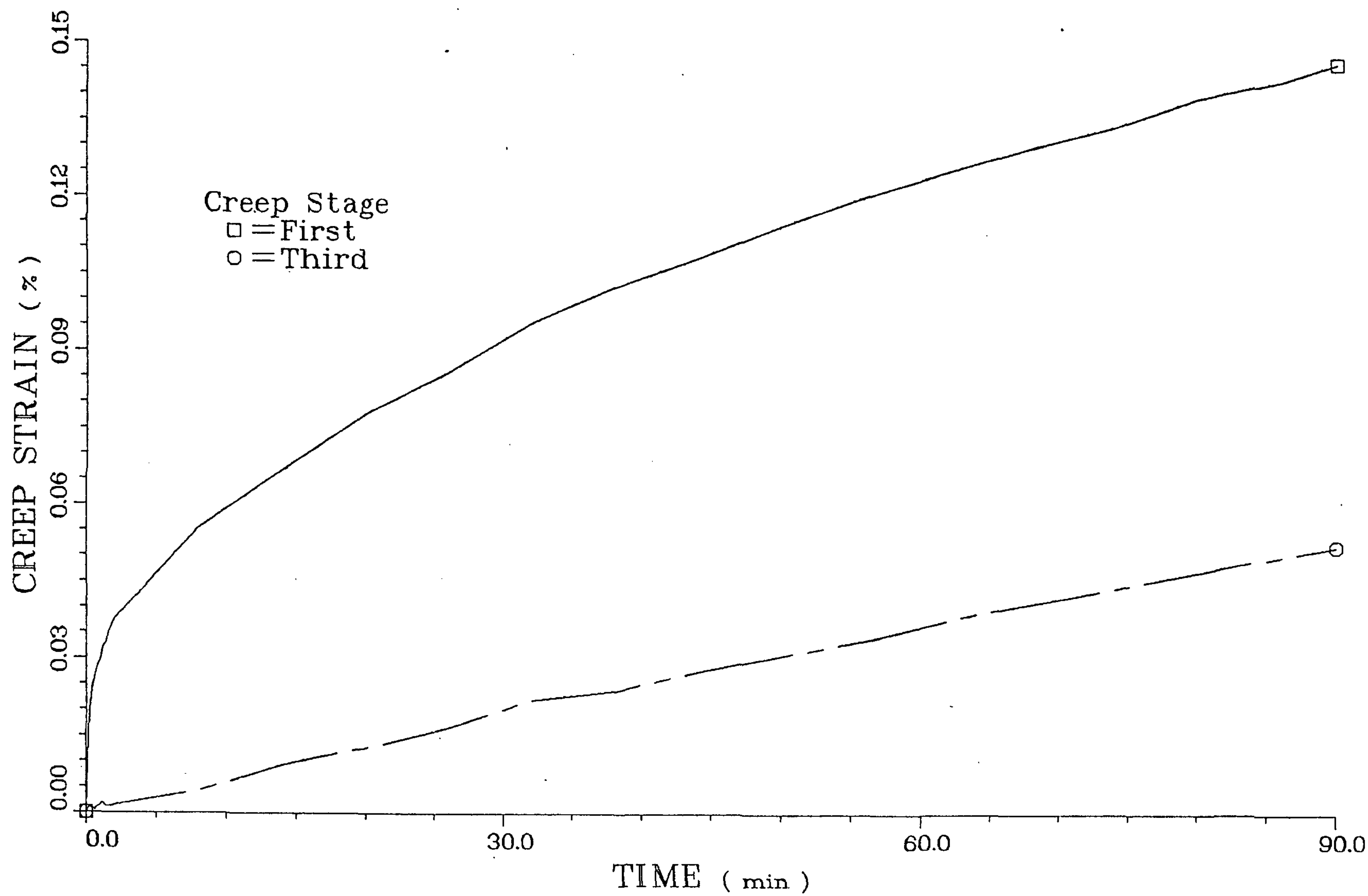

Fig 7: Creep Recovery Curves at 75.8MPa

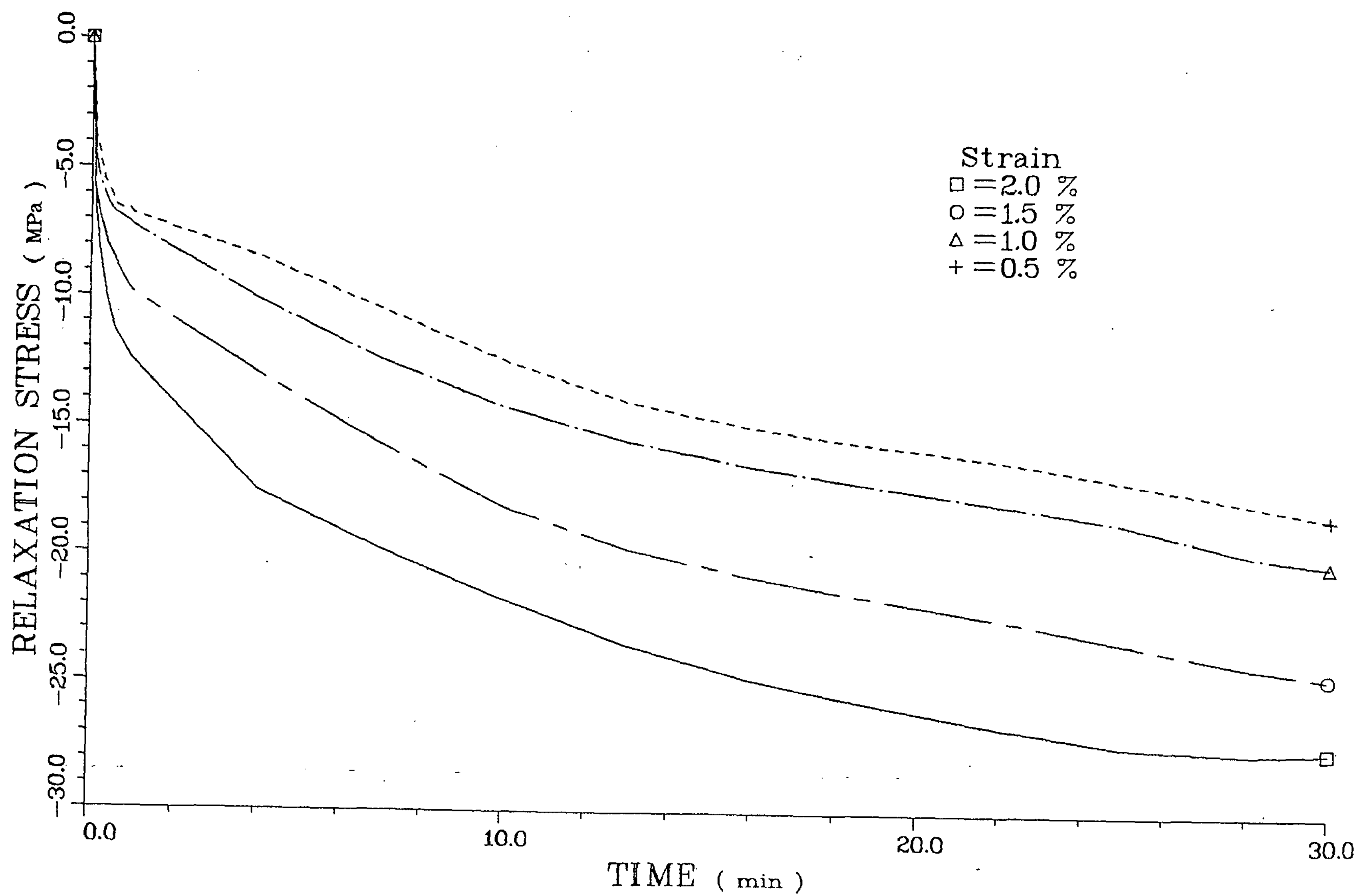

Fig 8: Relaxation Curves

Loading Strain Rate 10^{-3} s^{-1}

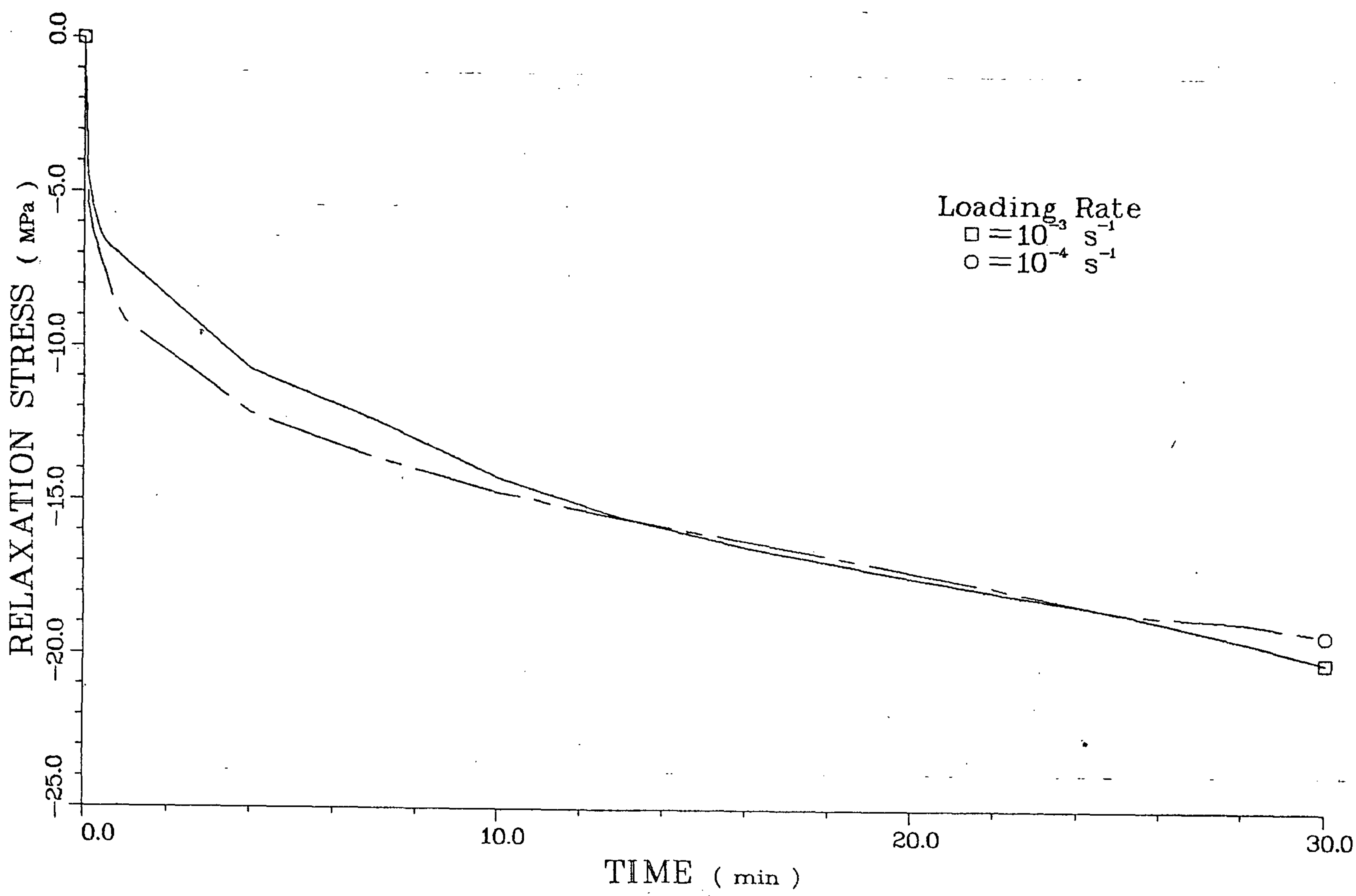

Fig 9: Relaxation Curves at 1.0% Strain

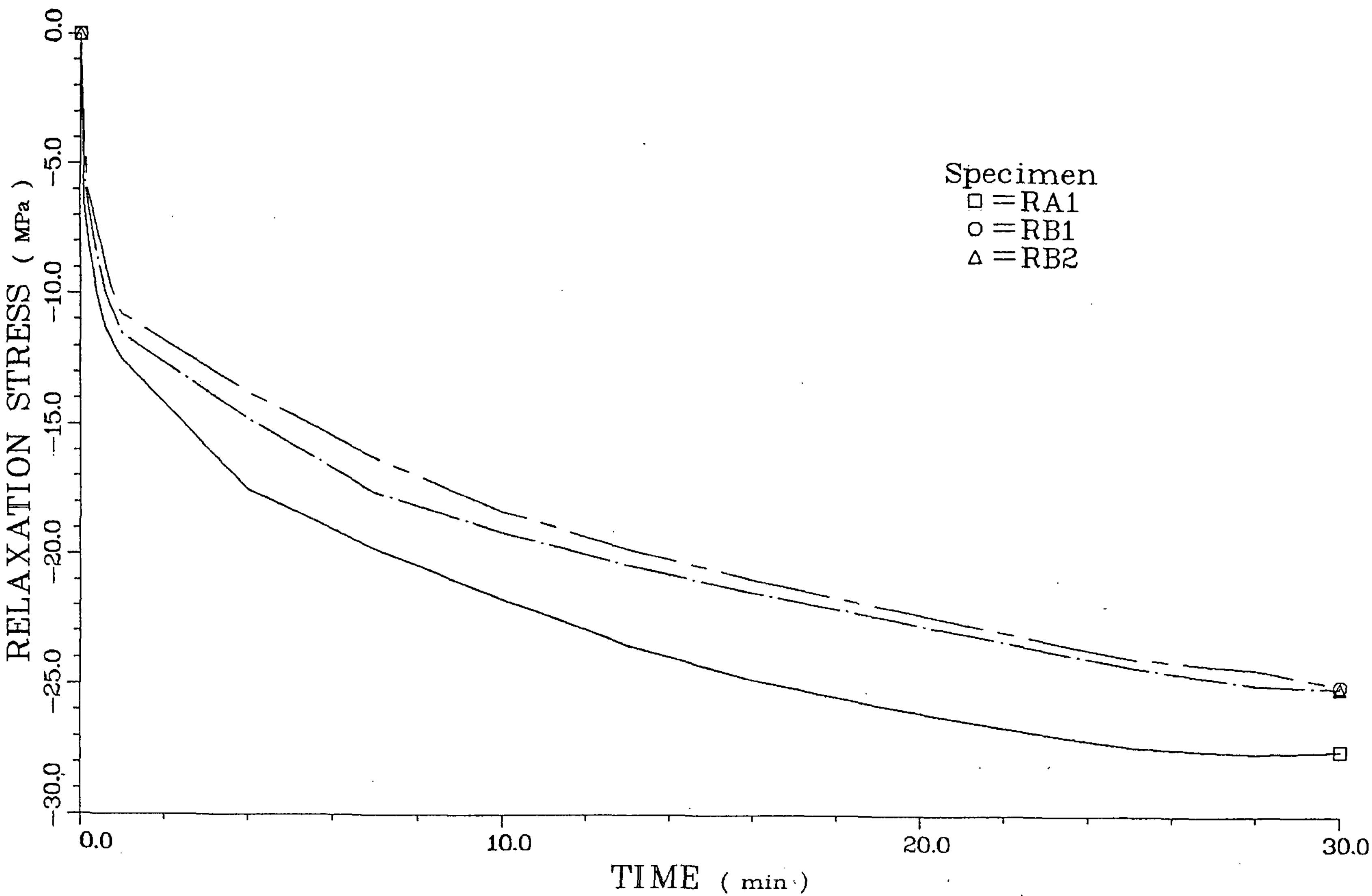

Fig 10: Relaxation Curves at 2.0% Strain

relaxation at 0.5% strain and RB2 had a first stage relaxation at 1.0% strain, the stress relaxation curves of RB1 and RB2 at 2.0% strain do not differ very much.

CHAPTER IV
CONCLUSIONS

Both the creep recovery and stress relaxation results suggest that the pre-loading strain-rate play an important role in the plastic deformation. Although for the material tested, i.e. Aluminum 6061 alloy, the strain-rate effect is not so significant in the strain-rate range of 10^{-3}-10^{-4} S^{-1}, the strain-rate affects the initial strain magnitude which in turn determines the subsequent creep recovery or stress relaxation behaviors.

Creep Recovery Behavior

Experimental results show that the magnitude of recovery strain is both influenced by the stress level and the amount of stress reduction. For the same loading strain-rate, the higher stress level generates higher recovery strain. Also, different stress drops will induce different creep recovery responses. Small stress drops cause positive forward creep, but large stress drops may induce negative creep recovery. This indicates the existence of a critical stress drop which corresponds to a neutral creep recovery phenomenon.

The preloaing strain rate does not have an apparent effect on the creep recovery strain when creep is tested at a low stress level. But the effect of preloading strain rate is significant when the stress level is high so that the initial plastic strain is large.

Relaxation Behavior

For the same loading strain-rate, the stress relaxation curves of different strain level have significantly different results. This suggested that the strain magnitude is an important factor in the investigation of stress relaxation.

Kujawski and Krempl [2] came to the conclusion from their investigation of Ti-7Al-2Cb-1Ta Titanium allly at room temperature that the amount of stress relaxation in a given period of time depends only on the preceding strain-rate but not the stress and strain at the start of relaxation. This result seems to be at variance with the present observation. However, it should be pointed out that in the experiments of Kujawski and Krempl, relaxation tests were preceded by a monotonic prestrain of 3.25%, which is different from the present tests in that the loading here was applied from the annealed status of material.

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