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SPECIAL PROJECT REPORT

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GEO

A LABORATORY INVESTIGATION ON THE DEVELOPMENT OF SURFACE RUSTING OF STEEL REINFORCEMENT BARS MANUFACTURED BY CONVENTIONAL HOT ROLLING METHOD AND BY THE TEMPCORE PROCESS

K.K. UY & W.C. LEUNG

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Materials Division

FOREWORD

At the request of the Standing Committee on Concrete Technology (SCCT), the Public Works Central Laboratory (PWCL) of the Materials Division carried out an investigation on the development of surface rusting of steel reinforcement bars produced by conventional hot-rolled method and by the Tempcore process. The main objective of the investigation is to compare the surface rusting of the two types of steel reinforcement bars under various exposure conditions.

The planning and overall supervision of this investigation was carried out by Mr W.C. LEUNG. Mr T.C. CHEUNG was responsible for the initial supervision of the laboratory work. Mr K.K. UY took over the supervision work from February 1995 and prepared this report in conjunction with Mr W.C. LEUNG. The assistance of the technical staff of the General Materials and Steel Testing Unit of the PWCL, including Messr C.T. KWOK, S.W. TAM and K.C. FOK is gratefully acknowledged.

P.L.R. PANG
Chief Geotechnical Engineer/Materials

ABSTRACT

Steel reinforcement bars manufactured by the Tempcore process are claimed by the manufacturers to have beneficial effects on the yield strength and bendability of the bars. However, these Tempcore bars appeared to develop surface rusting faster than bars manufactured by conventional hot rolling and in many instances they are rejected by the Engineer's supervisory staff on site because of their appearance. The Standing Committee on Concrete Technology's Sub-committee on Specification for Reinforcement requested the Public Works Central Laboratory (PWCL) to undertake a study on the development of surface rusting of reinforcement bars manufactured by conventional hot rolling and by the Tempcore process under various exposure conditions.

The PWCL conducted two series of exposure tests on the two types of bars. In the Series 1 study, the bars were kept in a ventilated room at the PWCL Building (next to the Kai Tak Nullah in Kowloon Bay) under ambient temperature and relative humidity conditions. In the Series 2 study, three groups of bars were subjected to different exposure conditions, ranging from completely sheltered conditions to direct exposure to the atmosphere.

The investigation showed that when both the conventional and Tempcore bars were kept under the same exposure conditions, the latter developed surface rusting faster than the former bars.

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1. INTRODUCTION

Steel manufacturing has undergone some changes in recent years. A new production method known as the "Tempcore" process is now gaining popularity among the steel manufacturers. The Tempcore process is claimed to be able to increase the yield strength and bendability of bars as well as to allow a wider choice of iron ore or scrap steel to be used.

The conventional method of producing deformed high yield steel bars is by the hot-rolled or the cold-worked method. Iron ore or scrap steel is usually melted in a furnace to form liquified ladle which flows through a continuous casting machine to form solidified steel billets. The billets are then processed through hot rolling or cold working to form deformed high yield steel bars.

In the hot-rolled process, the billets are first re-heated and then shaped to the specified requirements during hot rolling through a series of rolling mills. The continuous hot rolling reduces the chemical segregation and gives a reasonably consistent composition throughout the length of the steel bar.

The mechanical properties of the steel bar may be enhanced by the cold working technique. In this method, the steel billets are continuously cold stretched to form steel bars. After subjecting the bars to strain-hardening, the cold working process improves the ductility of the bars and removes all surface mill scale. The main drawback of the cold working technique is the lack of weldability of the steel bar.

The Tempcore process can be considered as a modification or derivation of the hot-rolled method. As the bar leaves the last stand of the hot rolling mill, it is passed through a special water cooling section, instead of being air cooled as in the hot-rolled method. The effect of water cooling is that the surface layer of the bar is quenched into martensite with the core remaining austenitic. The quenching treatment stops when a sufficient thickness of martensite has formed on the bar. When the bar leaves the water cooling section, the temperature gradient established in its cross section causes heat to flow from the centre to the surface. This increases the temperature of the surface layer resulting in self-tempering of the martensite. In fact, the name "Tempcore" has been chosen to reflect the fact that the martensitic layer is tempered by the hot core at the end of the quenching stage. Simon et al (1984) have indicated that the cooling process leads to an increase in yield strength of the bar by 150 to 230 MPa depending on the cooling intensity.

During a meeting of the Standing Committee on Concrete Technology (SCCT) Sub-committee on Specification for Reinforcement held on 20 January 1993, the stockists indicated that steel bars produced by the Tempcore process appeared to develop surface rusting faster than bars manufactured by the conventional hot-rolled process, and in many instances they were rejected by the Engineer's supervisory staff on site because of their appearance. The stockists, however, claimed that the surface rusting on the Tempcore bars does not affect the performance of the bars and that the surface rusting is of no structural concern. The Sub-committee members considered that there was a need to carry out a study to compare the development of surface rusting of the two types of bars under local storage conditions. The Public Works Central Laboratory (PWCL) was subsequent requested to undertake the study.

2. SCOPE OF STUDY

Two series of experiments were carried out by the PWCL:

(a) Series 1. The bars were stored in accordance with the requirements of the SCCT Subcommittee on Specification for Reinforcement (see Appendix 1). The bars were sheltered from direct sunlight and rain and stored under ambient temperature and relative humidity conditions. The surface rusting conditions of the two types of bars at various exposure times were compared.

Exposure commenced in May 1993 and was terminated in November 1994.

(b) Series 2. This was initiated by the PWCL. Having studied the initial results from the Series 1 study, it was decided that the Series 1 investigation should be augmented by another series of investigation in which the two types of bars were exposed to different exposure conditions ranging from completely sheltered conditions to direct exposure to the atmosphere. A limited study of the effect of chloride contamination on the surface rusting of steel bars was also carried out.

The Series 2 study commenced in November 1993 and was completed in November 1994.

3. MATERIALS

The conventional and Tempcore bars for the Series 1 study were supplied by Van Shun Cheong Hong Ltd. Upon receipt of the samples in February 1993, slight rust strains were observed on the conventional bars. Van Shun Cheong Hong Ltd was asked to check if other (unstained) conventional bars could be provided. The PWCL was advised that unstrained conventional bars manufactured within the same period as the Tempcore bars were not available. As such, the bars received were accepted for the investigation.

The bars for the Series 2 study were provided by Shiu Wing Steel Ltd.

4. METHODOLOGY

For the Series 1 study, the following were carried out:

(a) Six bars were selected for each manufacturing method, in pairs of 12 mm, 25 mm and 40 mm diameter.

(b) The samples were stored in a ventilated room at the ground floor level of the PWCL Building (see Plates 1 and 2), under ambient temperature and relative humidity conditions, but sheltered from direct exposure to sunlight and rain.

(c) Photographs were taken at about monthly intervals for a period of over one year.

For the Series 2 study, there were three groups of bars for exposure testing. Each group consisted of one conventional and one Tempcore bar, both of 40 mm diameter. The three groups of bars were subjected to different exposure conditions as detailed below:

Group 1 : The bars were directly exposed to the atmosphere.

Group 2 : The bars were stored under sheltered conditions, similar to the Series 1 investigation. This serves as a check for the previous results.

Group 3 : The bars were first immersed in a 3.5% sodium chloride solution for two days to simulate chloride contamination. The bars were then put in the same exposure conditions as bars in Group 2.

Group 2 and 3 bars were stored inside a purpose-built ventilated shed located on the roof top of the PWCL Building. The Group 1 bars were stored on top of the shed (see Plates 31 and 32). The rusting developed on the surface of the bars was recorded by taking photographs at about monthly intervals.

5. RESULTS

5.1 Series 1 Study

The monthly average, maximum and minimum temperature and relative humidity at the storage location, as recorded between May 1993 and April 1994, are given in Table 1.

The results of the 12 mm diameter bars are discarded because the extent of surface rusting on the bars, especially on the Tempcore bars, at the beginning of the experiment is considered to give bias results.

Photographs of the 40 mm diameter and 25 mm diameter bars, taken between June 1993 and November 1994, are shown in Plates 3 to 30.

5.2 Series 2 Study

Photographs of the development of rusting for Groups 1, 2 and 3 bars are shown in Plates 33 to 38, 39 to 44 and 45 to 49 respectively.

Being next to the Kai Tai Nullah at Kowloon Bay, the atmosphere in the area is known to be fairly corrosive.

5.3 The Rust Guide

The Rust Guide for Steel Reinforcement Bars in Appendix 15A of the Guidance Notes to the General Specification (GS) for Civil Engineering Works (Hong Kong Government, 1992) is reproduced in Plates 50 and 51 for reference by readers of this Report. Based on the Guidance Notes, bars Nos. 1 to 6 in Plate 50 are classified to have corroded to an extent which renders them unsuitable for use in construction works. Bars Nos. 7 to 18 are acceptable.

6. DISCUSSION

6.1 Series 1 Study

After about seventeen months of storage, it was found that the surface rusting of the conventional bars had not increased significantly. For the 40mm bars, the rusting was very insignificant (see Plates 3 and 15). The same conclusion can be drawn from Plates 17 and 29 for the 25mm conventional bars.

For the Tempcore bars, a very slight increase in surface rusting was observed after six months of storage as revealed by comparing Plates 4 and 8 for the 40mm bars and Plates 18 and 22 for the 25mm bars. However, even after seventeen months of storage, the increase in surface rusting was by no means significant as shown by comparing Plates 4 and 16 for the 40mm bars and Plates 18 and 30 for the 25mm bars.

Compared with the bars in the Rust Guide of the GS Guidance Notes (see Plates 50 and 51), the surface rusting of the conventional bars after seventeen months of storage was found to be similar to that of bars Nos. 11 and 12 on the Rust Guide. They are therefore acceptable for use in construction works. For the Tempcore bars, the surface rusting condition after seventeen months of storage was found to be similar to bars Nos. 9 and 10 on the Rust Guide. They are therefore also acceptable.

6.2 Series 2 Study

6.2.1 Group 1 bars (i.e. bars directly exposed to the atmosphere)

At the beginning of the experiment, the surface of the conventional bar was slightly rusty but the Tempcore bar was rustless, as shown in Plates 33 and 34 respectively. After two months of exposure, it was found that the two bars had rusted to approximately the same degree by comparing the bars in Plate 35. After four months of storage, the rusting on the Tempcore bar was slightly more severe than that of the conventional bar (see Plate 36). After seven months of exposure, the surface condition of the Tempcore bar was worse than that of the conventional bar as shown in Plate 37. The surface rusting of the conventional and Tempcore bars was found to be similar to that of bars No. 8 and 7 respectively in the Rust Guide (see Plates 50 and 51). Both bars are therefore acceptable for use in construction works.

Compared with the bars in the Rust Guide, the condition of surface rusting of the conventional bar after nine months of exposure (see Plate 38) was found to be similar to that of bar No. 7 in the Rust Guide. It is therefore acceptable for use. For the Tempcore bar, the surface rusting after nine months of exposure (see Plate 38) was found to be similar to bar No. 6 in the Rust Guide. It is therefore (marginally) not acceptable.

6.2.2 Group 2 bars (i.e. bars stored under sheltered conditions)

At the beginning of the experiment, the surface of the conventional bar was slightly rusty but the Tempcore bar was rustless as shown in Plates 39 and 40 respectively. After two months of storage, the two bars was found to have similar amount of surface rusting (see Plate 41).

The condition of the bars after twelve months of storage is shown in Plate 44. The Tempcore bar was found to have slightly more surface rusting than the conventional bar. Both bars had similar rusting condition as bar No. 9 in the Rust Guide. Hence, they are both acceptable for use in construction works.

6.2.3 Group 3 bars (i.e. salt contaminated bars stored under sheltered conditions)

At the beginning of the experiment, the surface of the conventional bar was slightly rusty but the Tempcore bar was rustless as shown in Plates 45 and 46 respectively. After four months of storage, the Tempcore bar had slightly more surface rusting than the conventional bar (see Plate 47). The surface rusting condition of the conventional bar after nine months of storage (see Plate 49) was similar to that of bar No. 8 in the Rust Guide. The bar is therefore considered acceptable for use in construction works. The surface rusting condition of the Tempcore bar after nine months of storage (see Plate 49) was similar to that of bar No. 7 in the Rust Guide. Therefore, it is also considered acceptable.

7. CONCLUSIONS

In response to the request of the Standing Committee on Concrete Technology, the PWCL has carried out a series of exposure tests to compare the development of surface rusting of conventional bars and Tempcore bars. Based on the results of the exposure tests, the following conclusions can be drawn :

(a) After seventeen months of storage in a ventilated room at the PWCL Building (next to the Kai Tak Nullah in Kowloon Bay), under ambient temperature and relative humidity conditions, the surface rusting conditions of both the conventional and Tempcore bars were found to be acceptable for use in construction works. The Tempcore bars had a slightly higher rusting rate than the conventional bars.

(b) After storage under sheltered conditions at the roof top of the PWCL Building for twelve months, both the conventional and Tempcore bars were found to be acceptable for use in construction works.

(c) For chloride contaminated bars stored under sheltered conditions for nine months, both the conventional and Tempcore bars were also found to be in an acceptable condition for use in construction works.

(d) After direct exposure to the atmosphere on the roof top of the PWCL Building for nine months, the surface rusting condition of the conventional bars was found to be acceptable. However, the Tempcore bars rusted to an unacceptable condition, rendering them unsuitable for use in construction works.

(e) When kept under the same exposure conditions, the Tempcore bars were found to develop surface rusting faster than the conventional bars.

8. REFERENCES

Simon, P., Economopoulos, M. & Nilles, P. (1984). TEMPCORE: an economical process for the production of high quality rebars. MPT-Metallurgical Plant and Technology, Issue No. 3/84, Centre de Recherches Metallurgiques (C.R.M.), Liege, Belguim, pp 80-93.

Hong Kong Government (1992). General Specification for Civil Engineering Works. Guidance Notes. Government Printer. Hong Kong.

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Table 1 - Record of Temperature and Relative Humidity for Series 1 Study

Month	Temperature (°C)			Relative Humidity (%)		
	Average	Maximum	Minimum	Average	Maximum	Minimum
May 93	25.0	28.5	21.7	81	86	73
Jun 93	26.7	28.7	25.1	81	85	77
Jul 93	28.5	32.0	25.2	80	84	78
Aug 93	26.9	28.1	25.8	81	86	76
Sep 93	27.6	29.7	25.0	74	89	63
Oct 93	26.4	28.2	24.2	62	78	40
Nov 93	21.7	26.3	14.2	73	88	60
Dec 93	20.5	28.5	14.2	60	79	42
Jan 94	19.1	22.5	14.3	62	76	46
Feb 94	18.2	21.0	15.0	65	75	55
Mar 94	23.0	26.0	19.0	64	81	50
Apr 94	28.0	31.0	25.0	78	88	71

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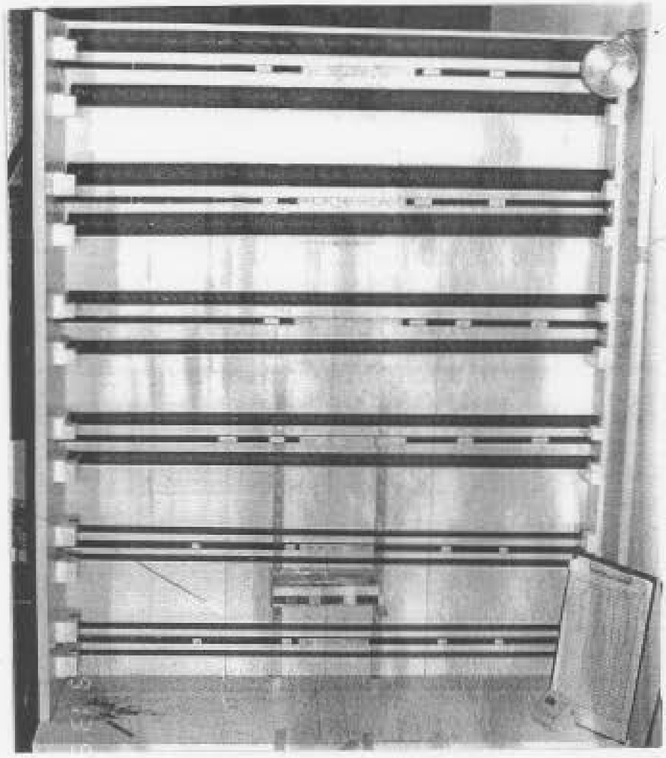

Plate 1 - Holding Rack with Hydrometer and Thermometer at the Top and Lower Right Corner Respectively

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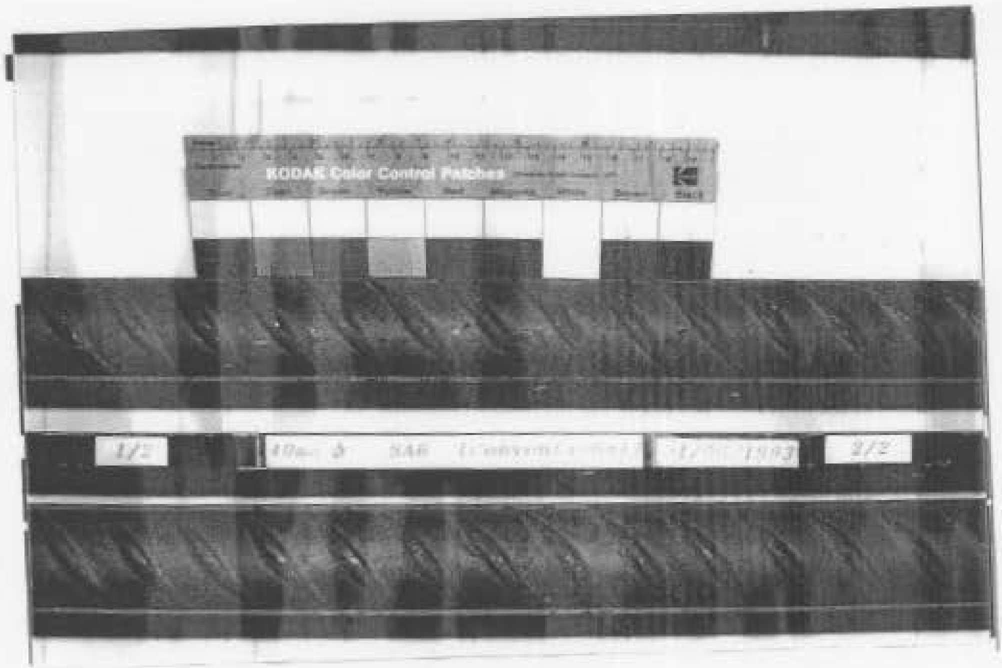
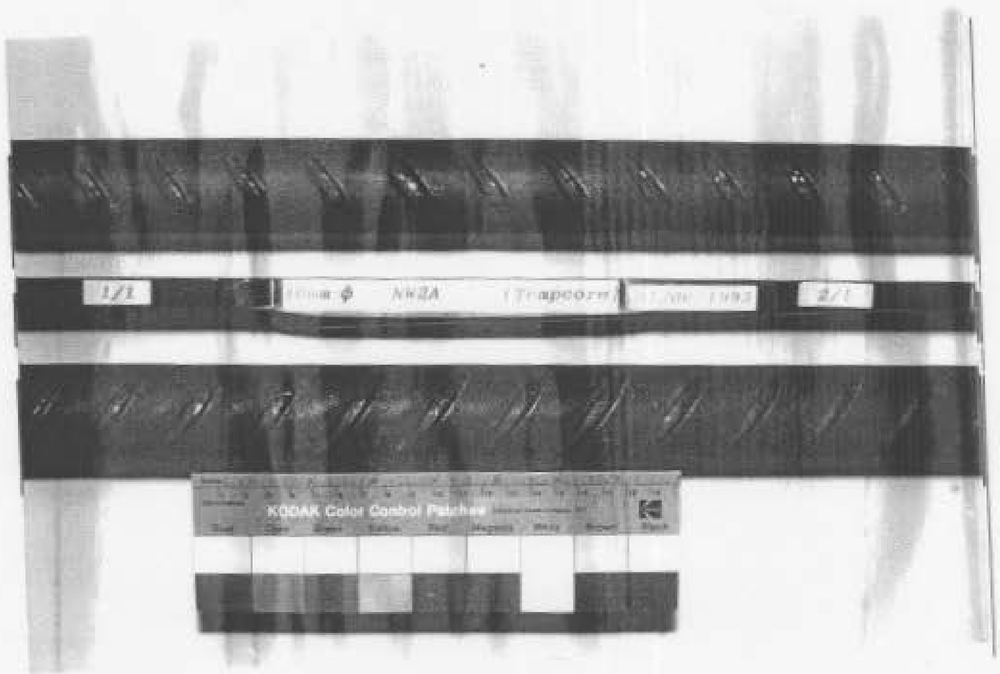


Plate 3 - Series 1, Conventional Bars, Size 40 mm
(taken on 1/6/93)



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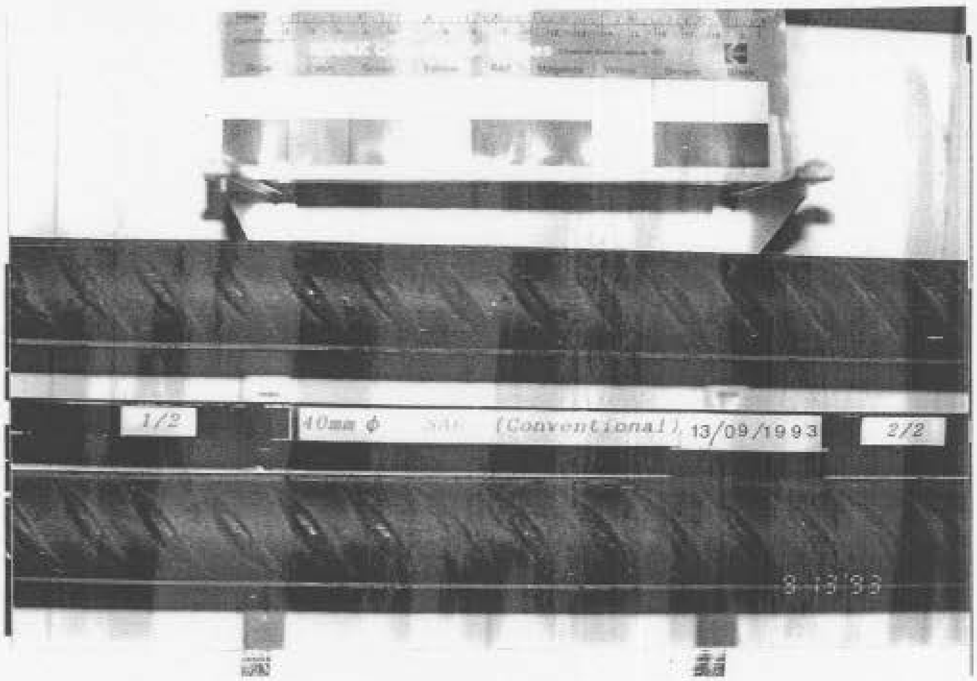
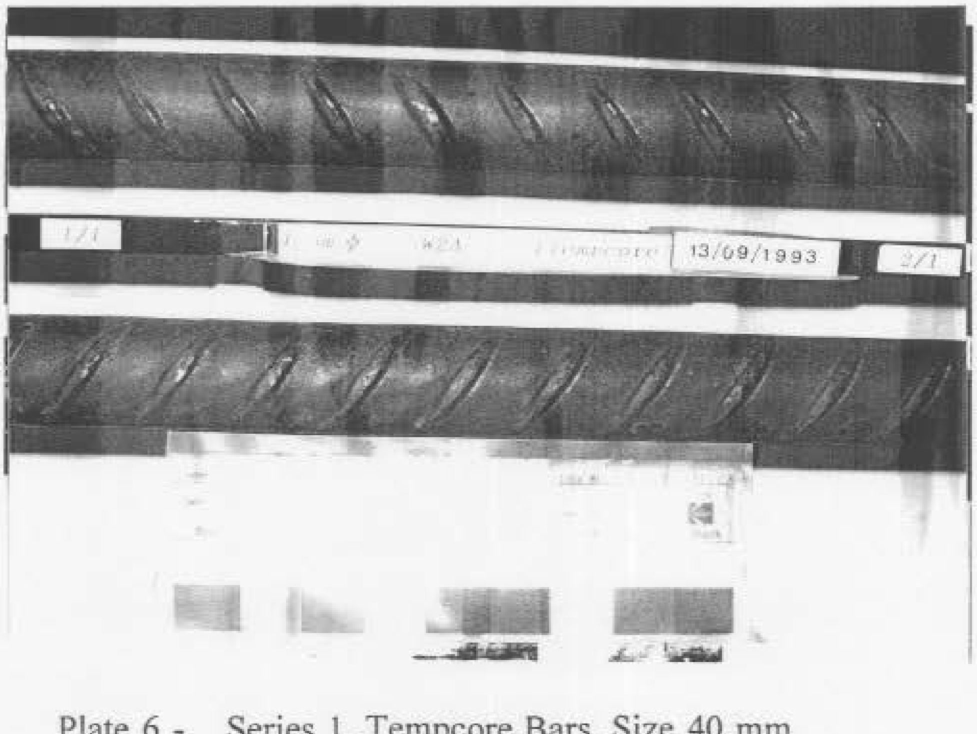


Plate 5 - Series 1, Conventional Bars, Size 40 mm (taken on 13/9/95)



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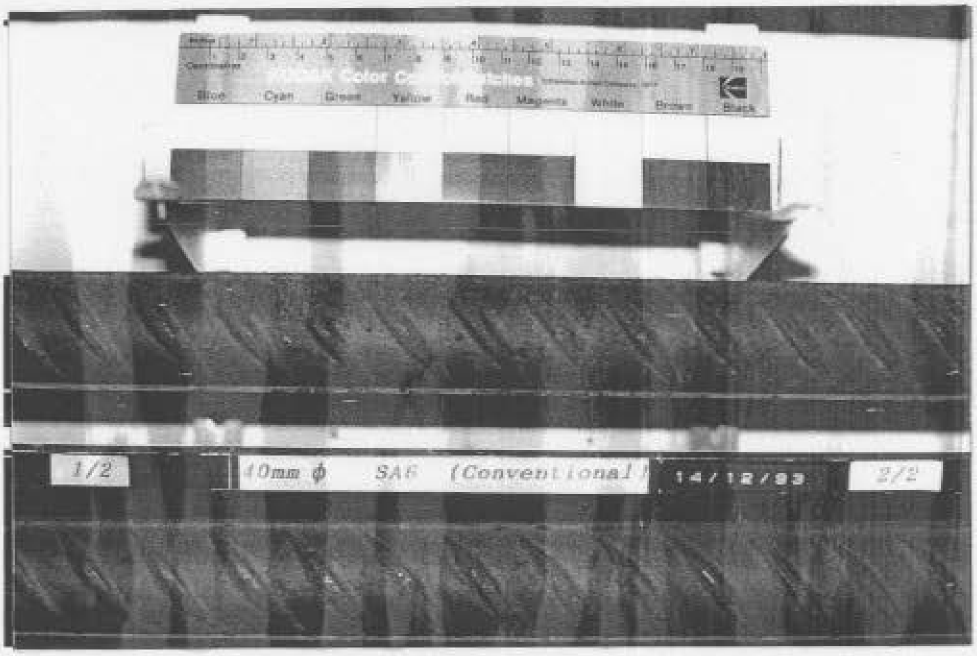

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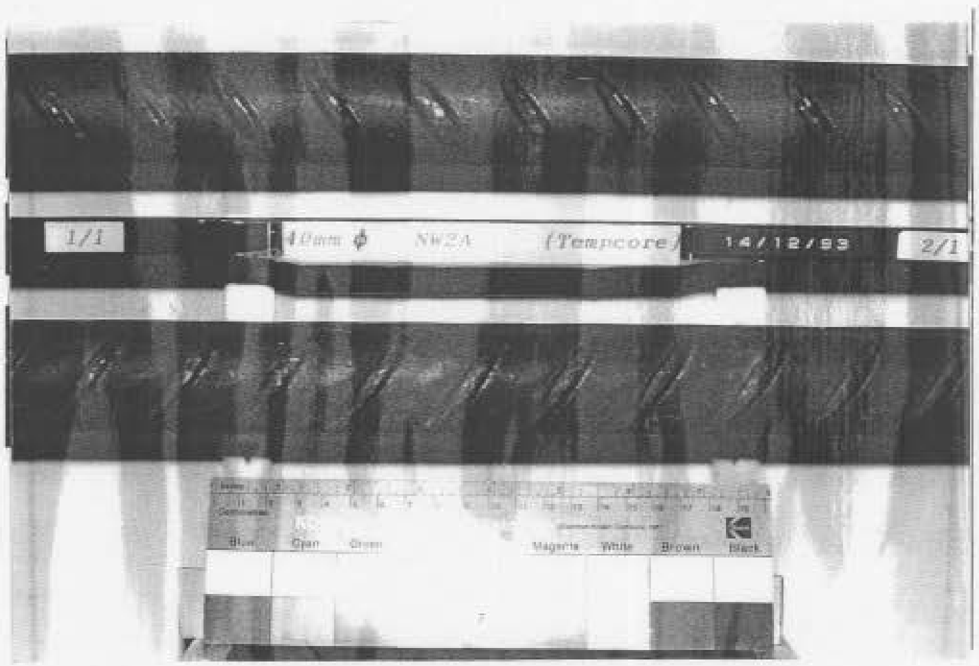

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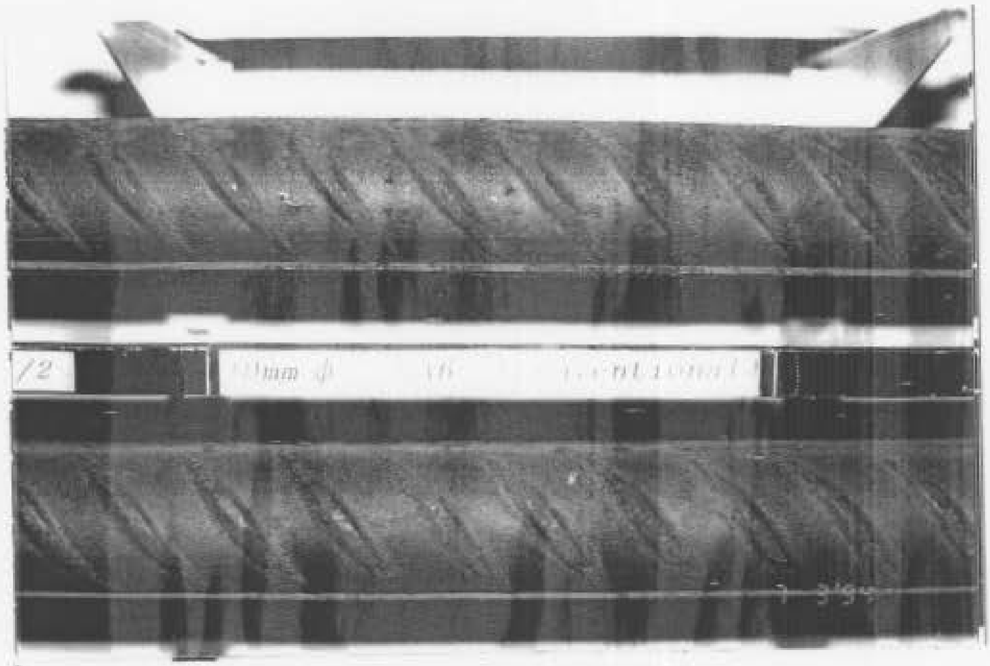

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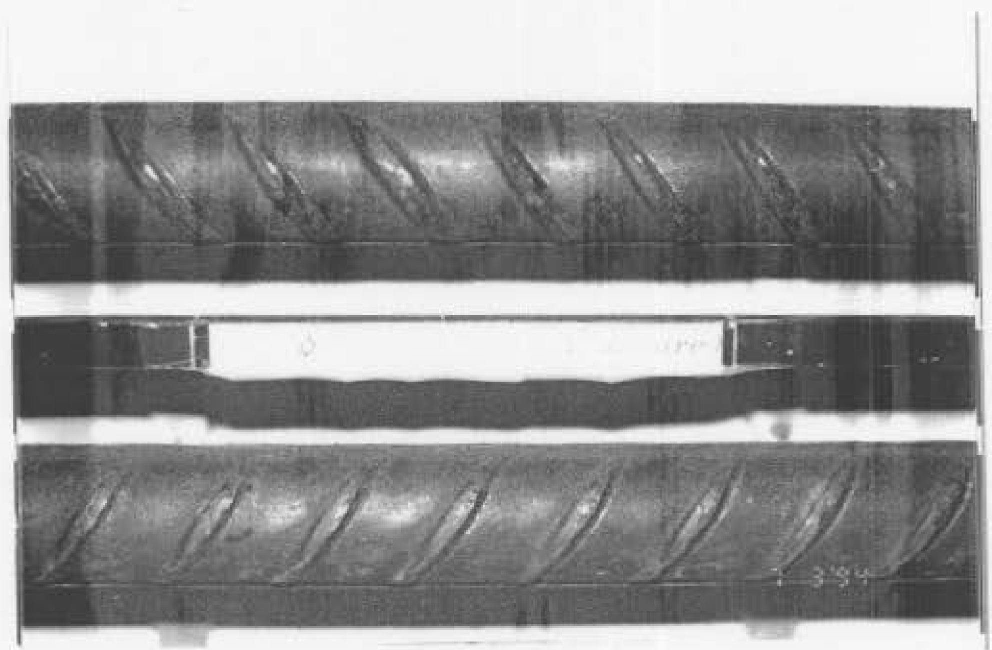

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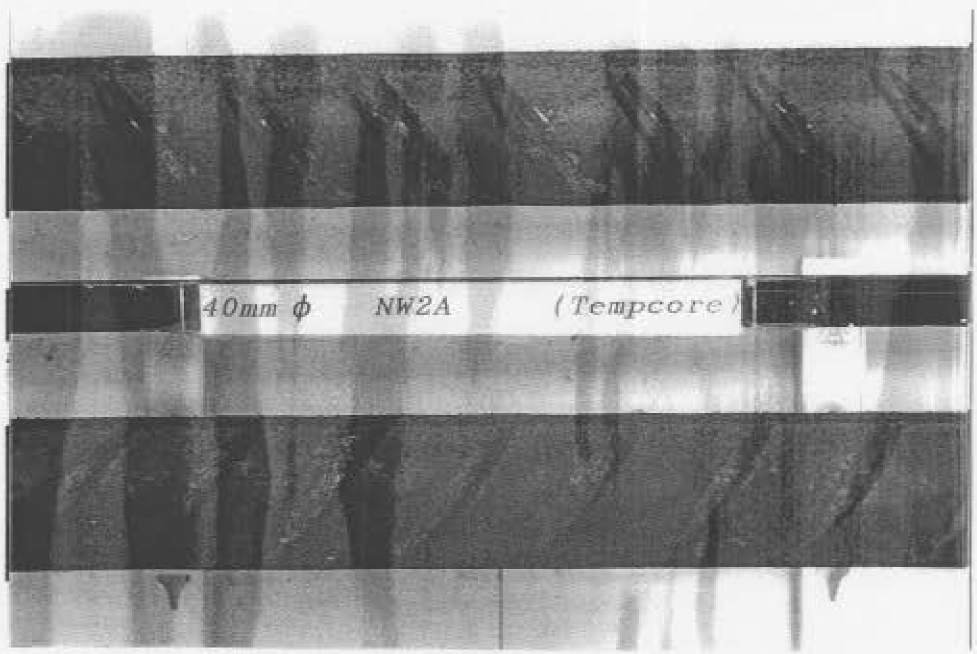

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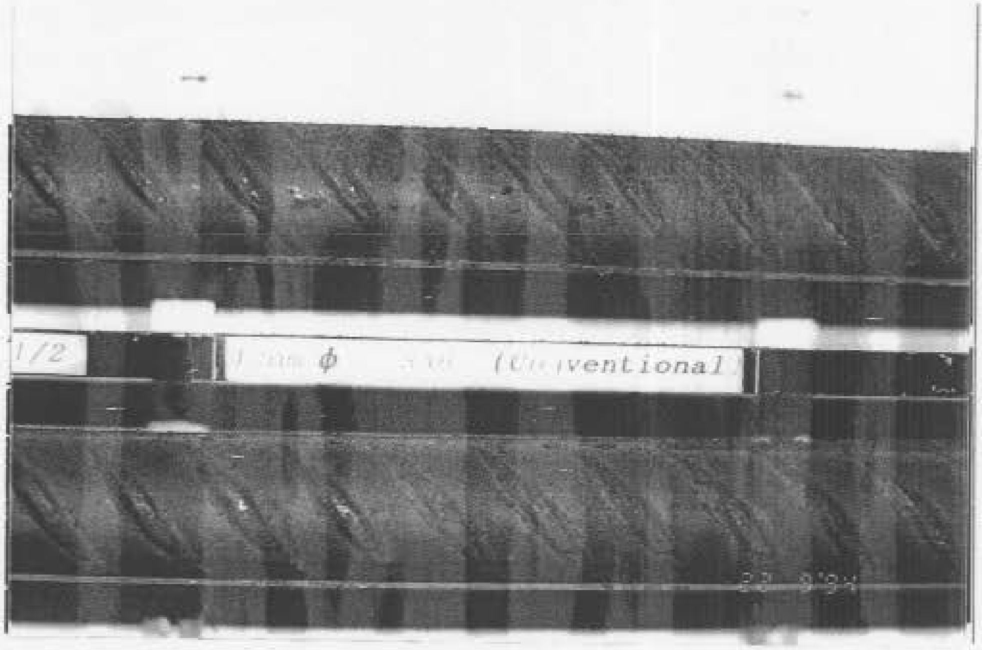

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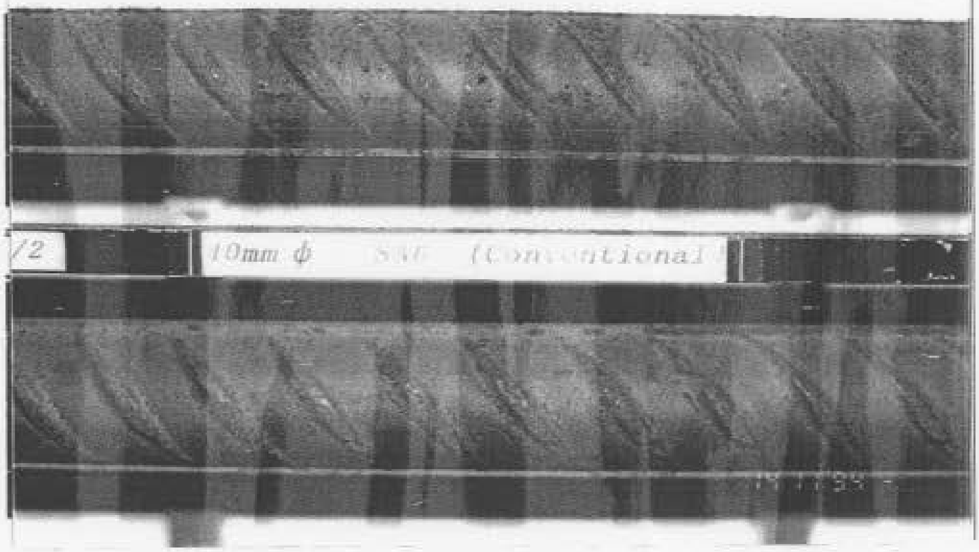

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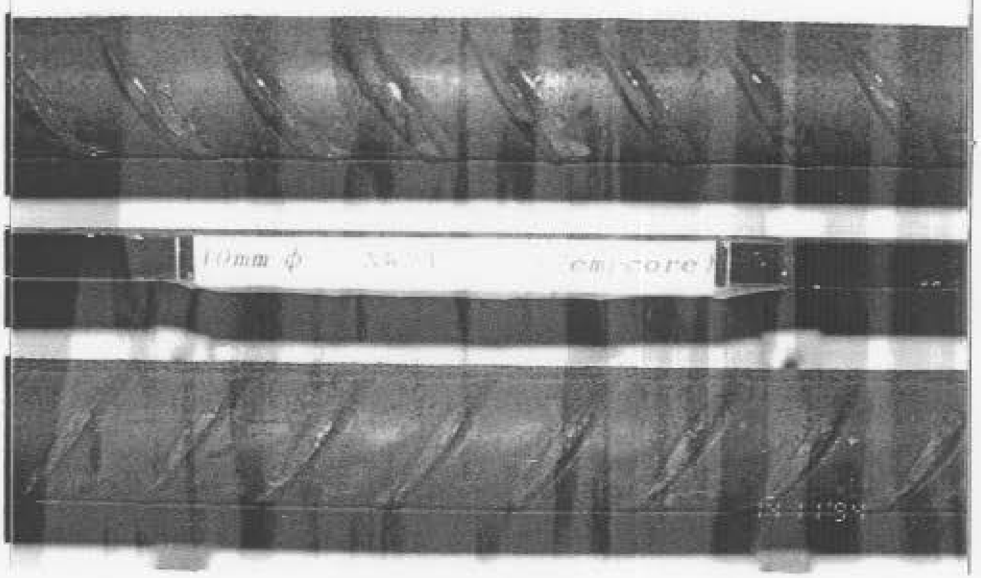

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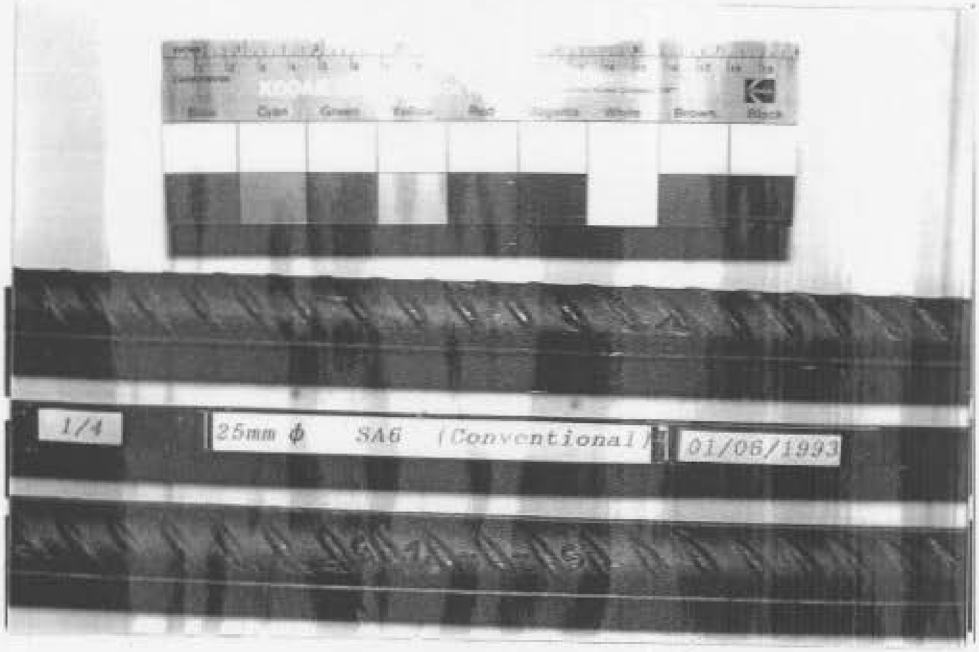

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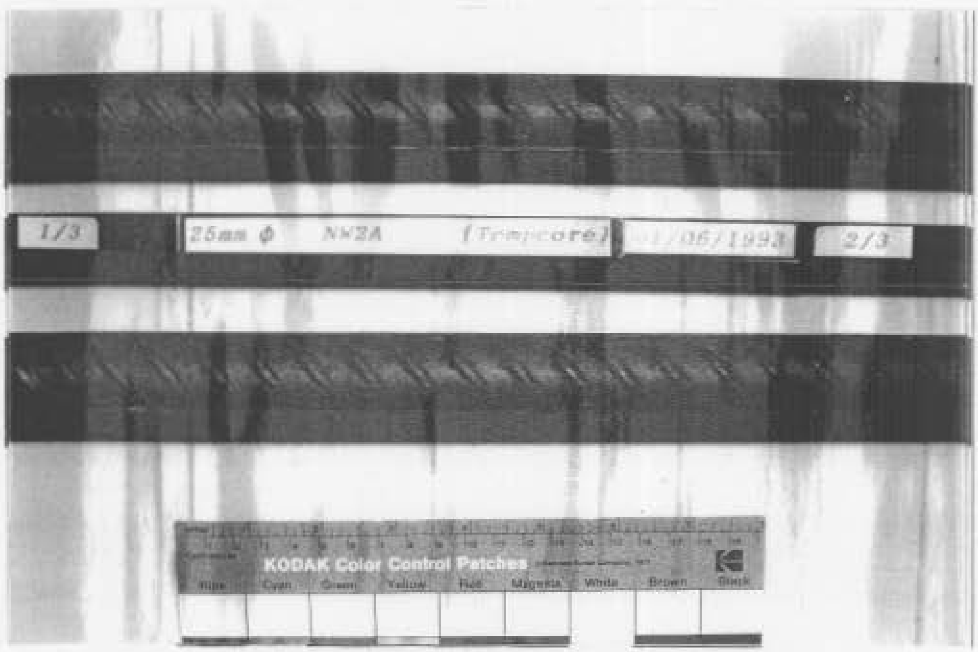

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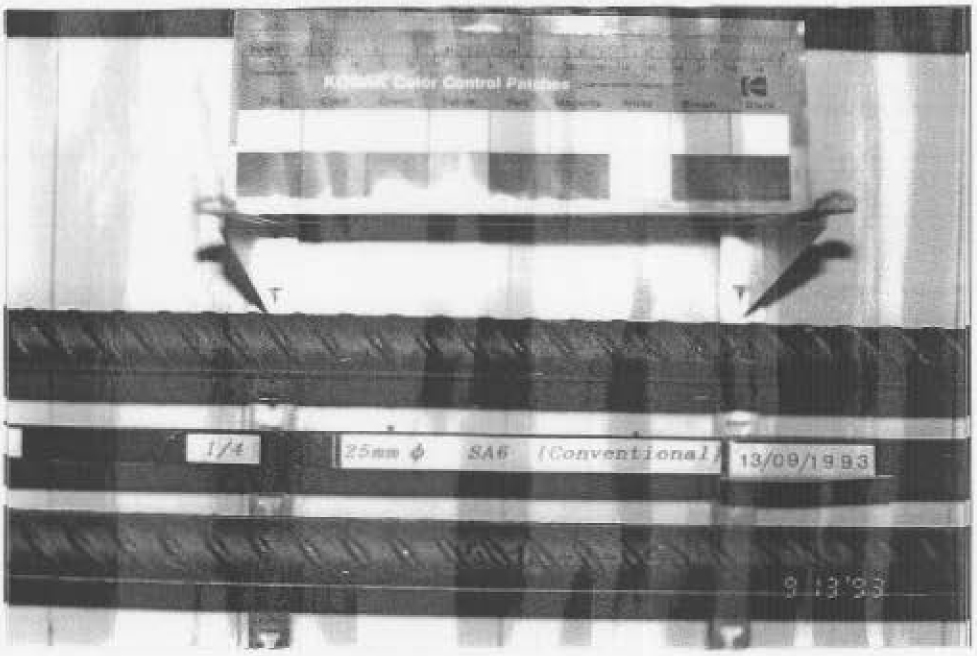

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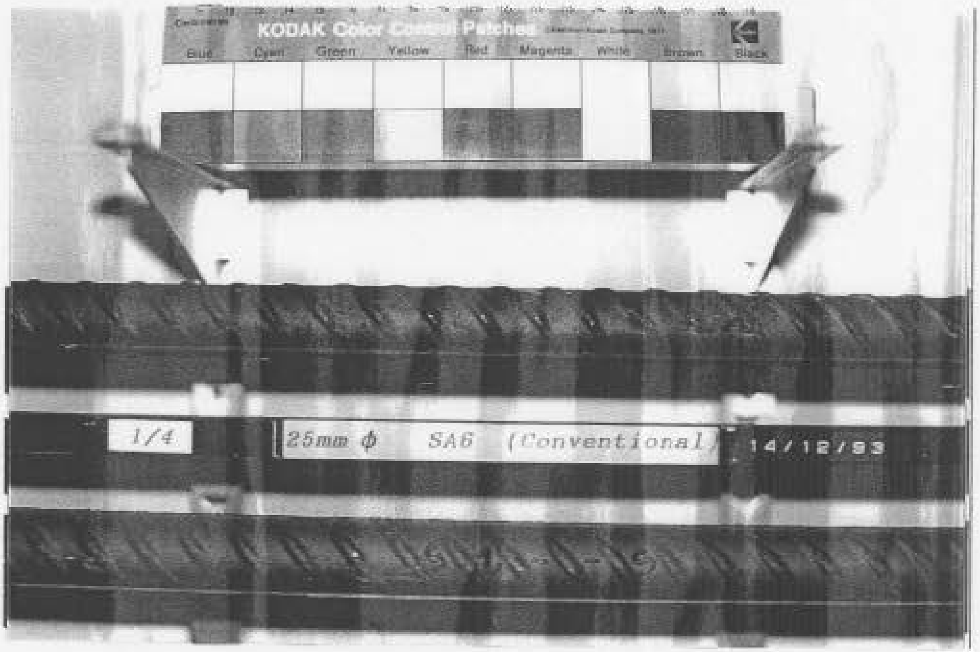

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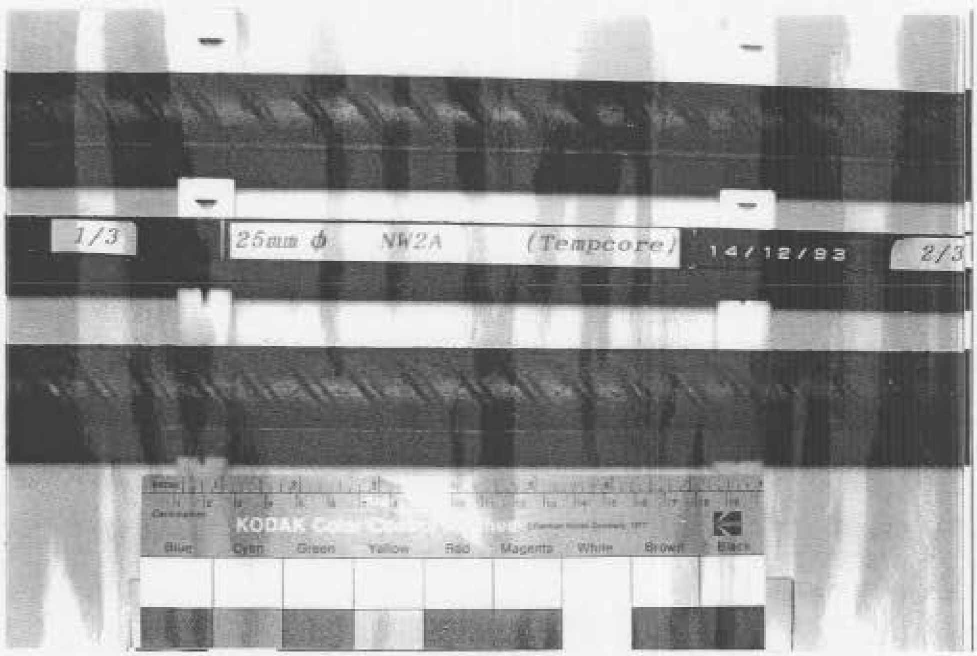

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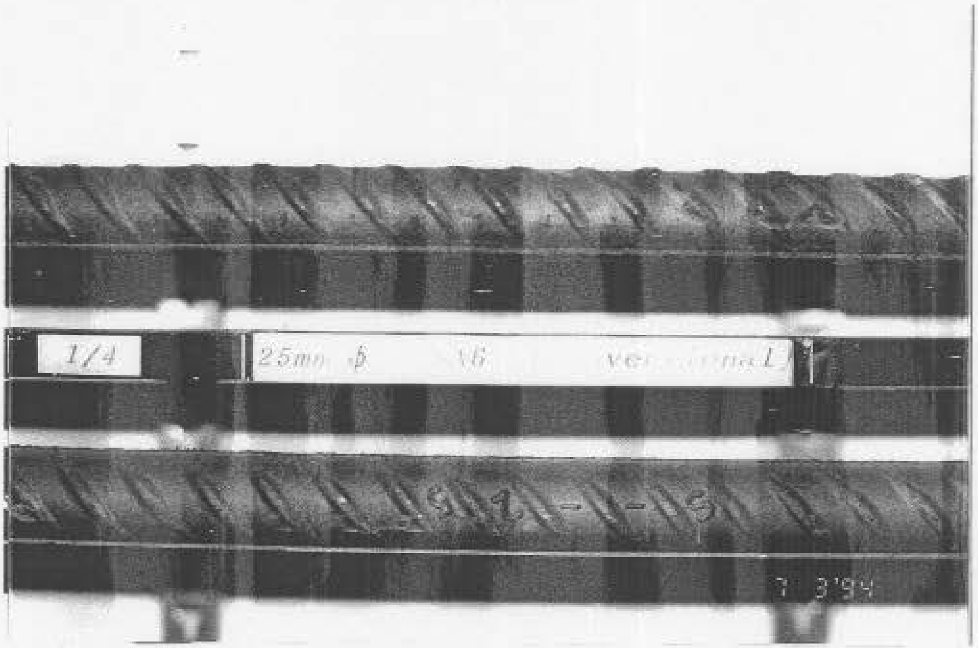

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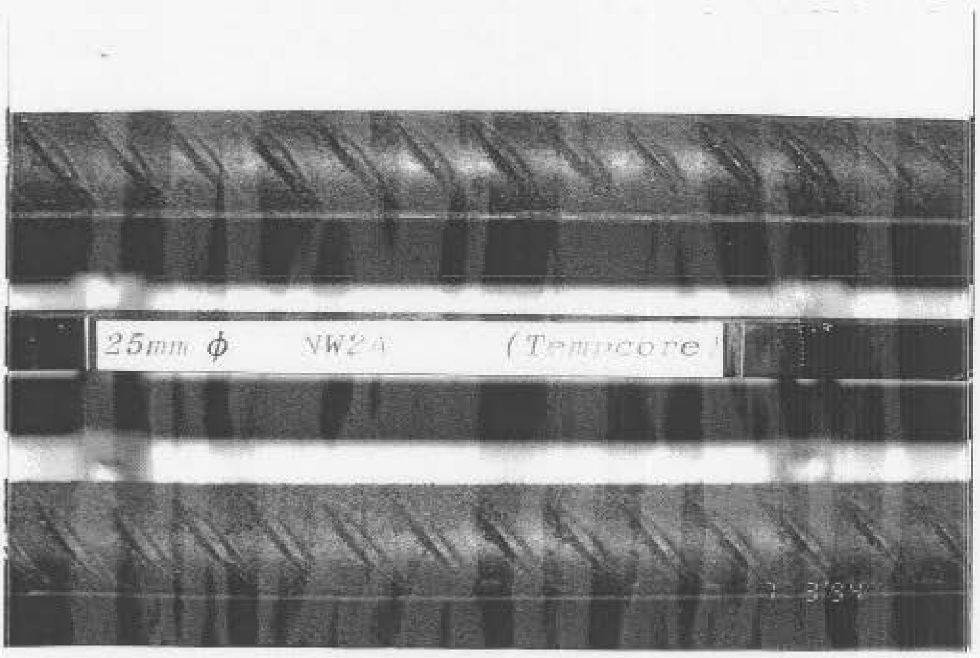

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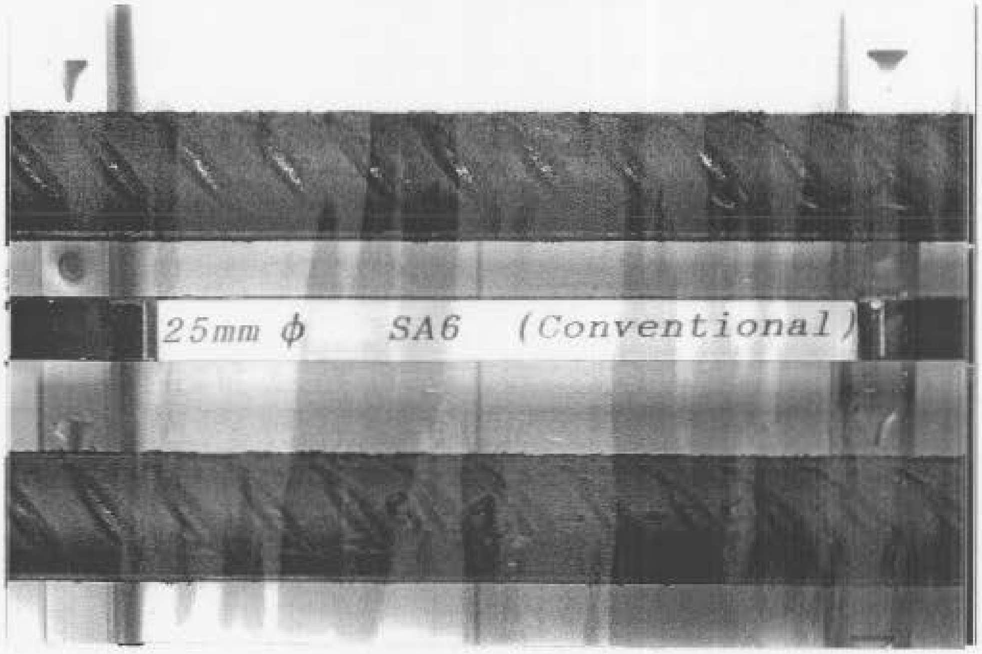

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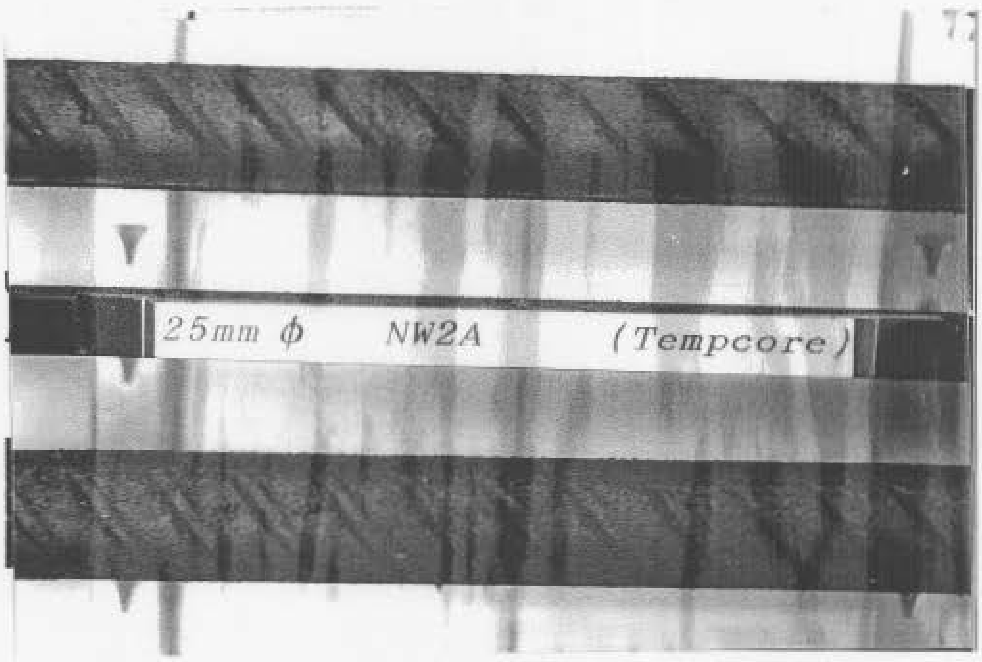

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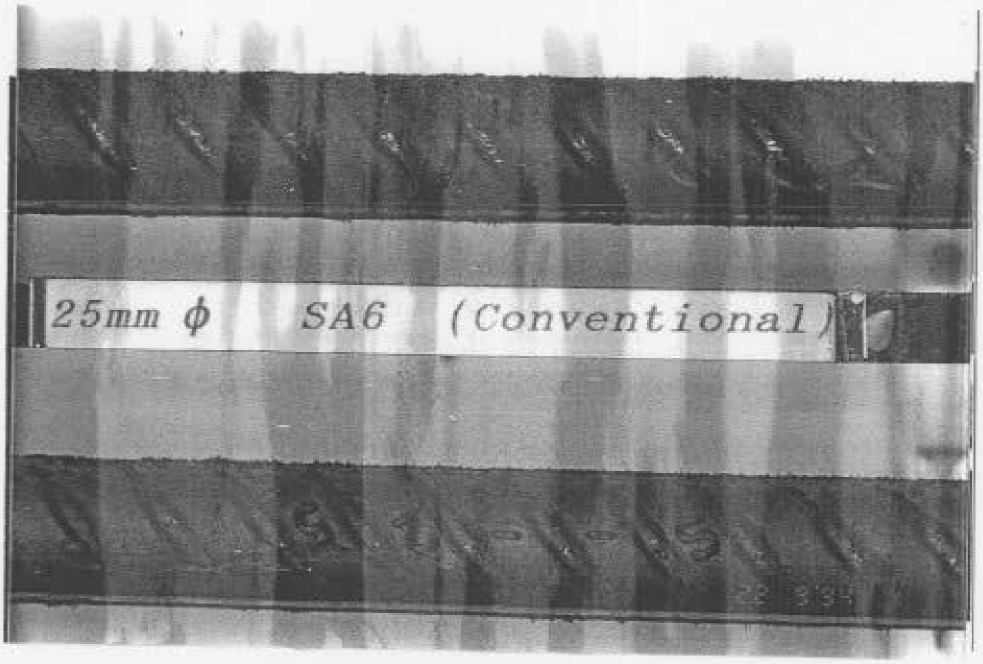

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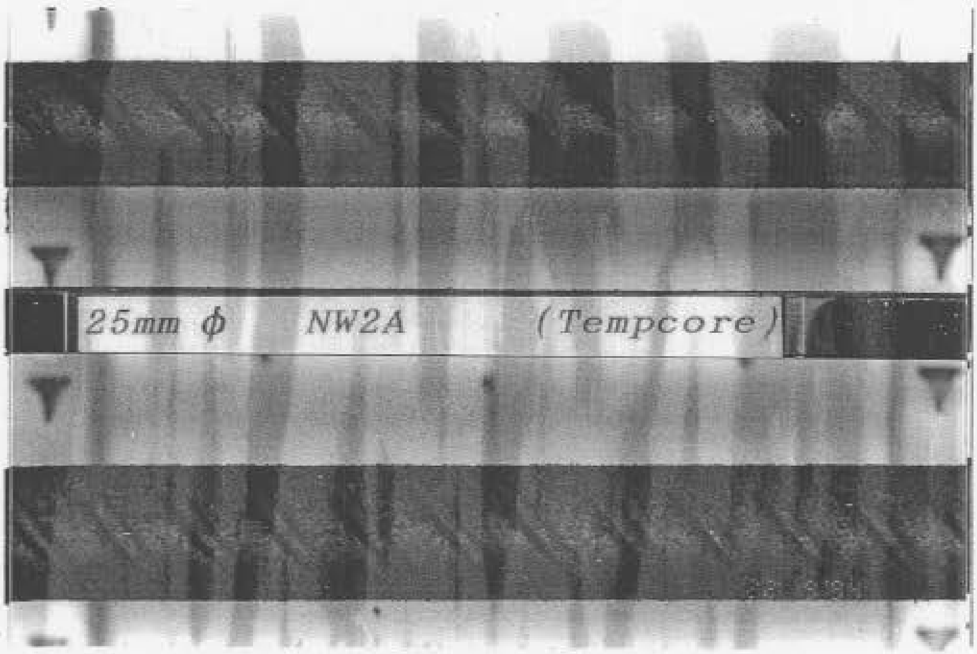

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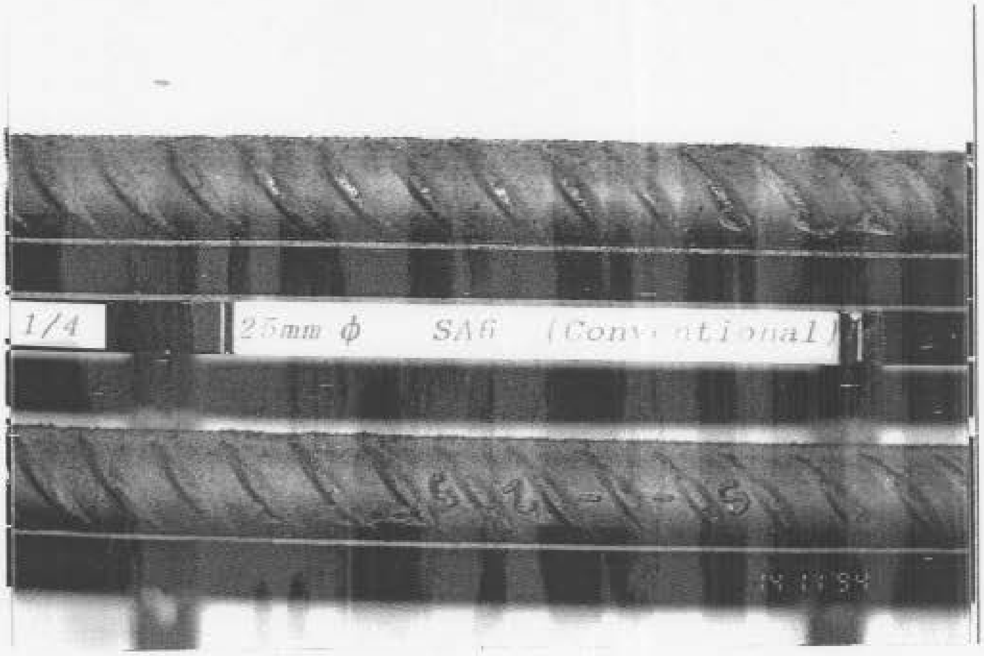

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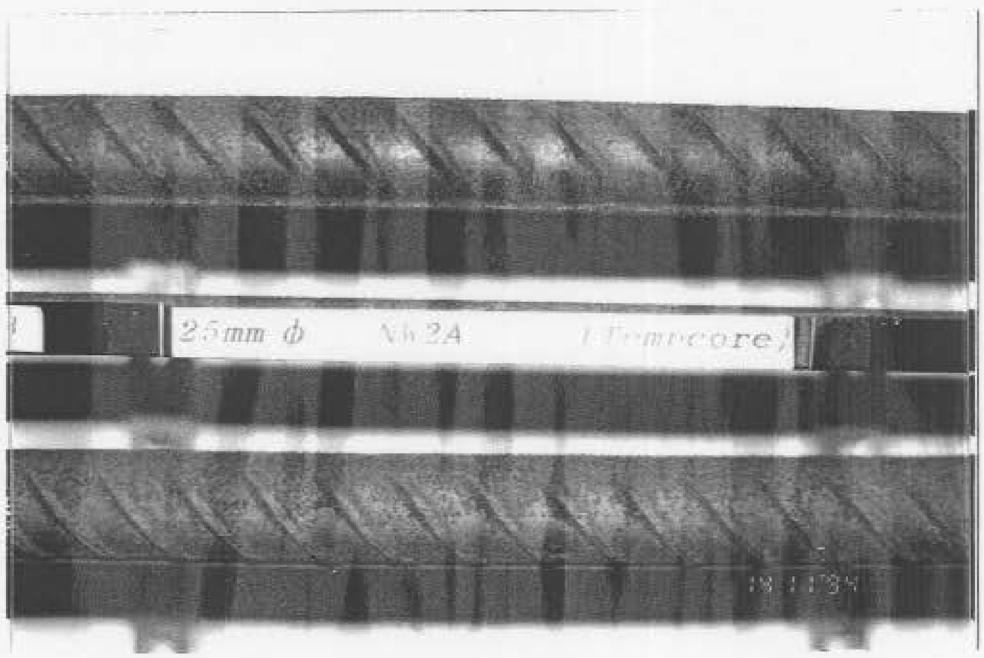

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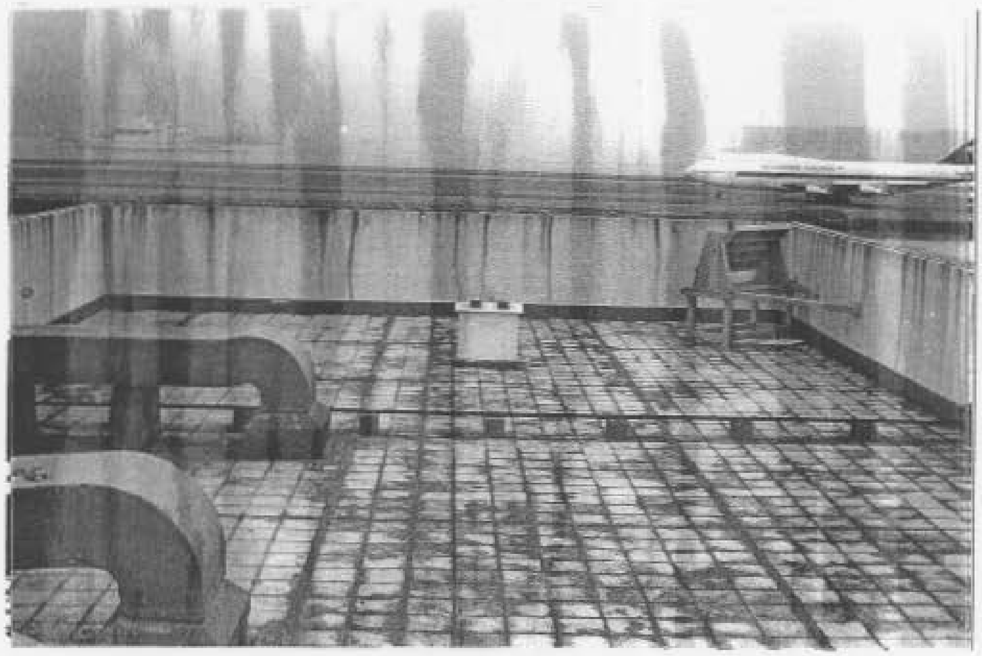

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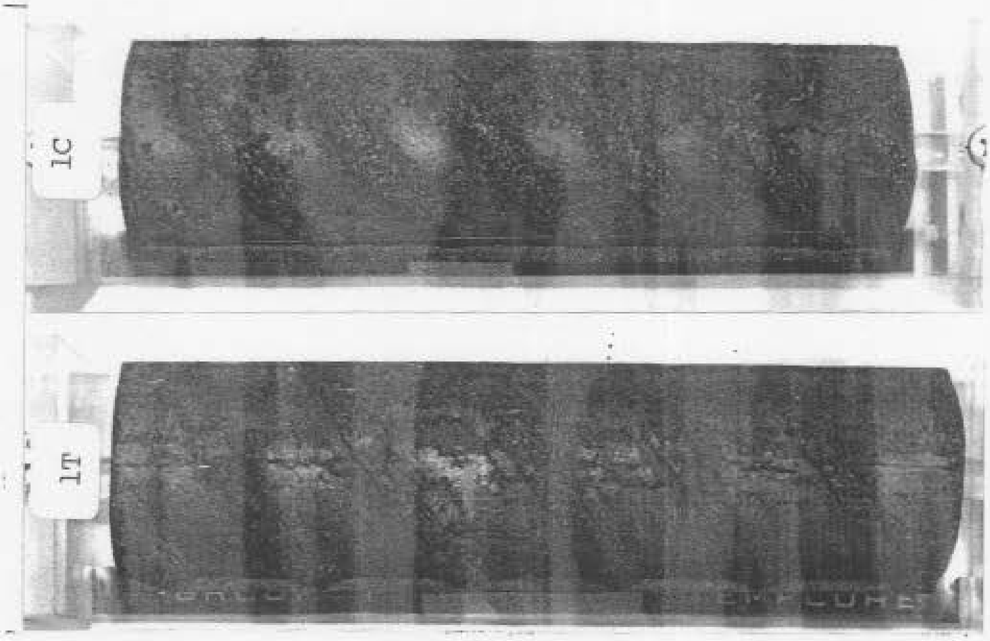

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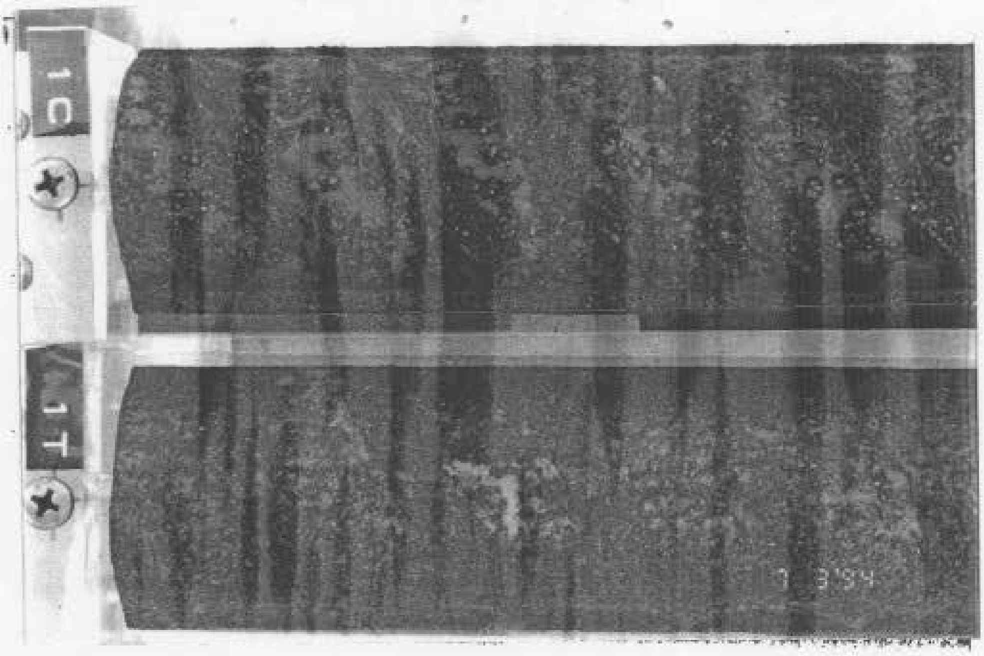

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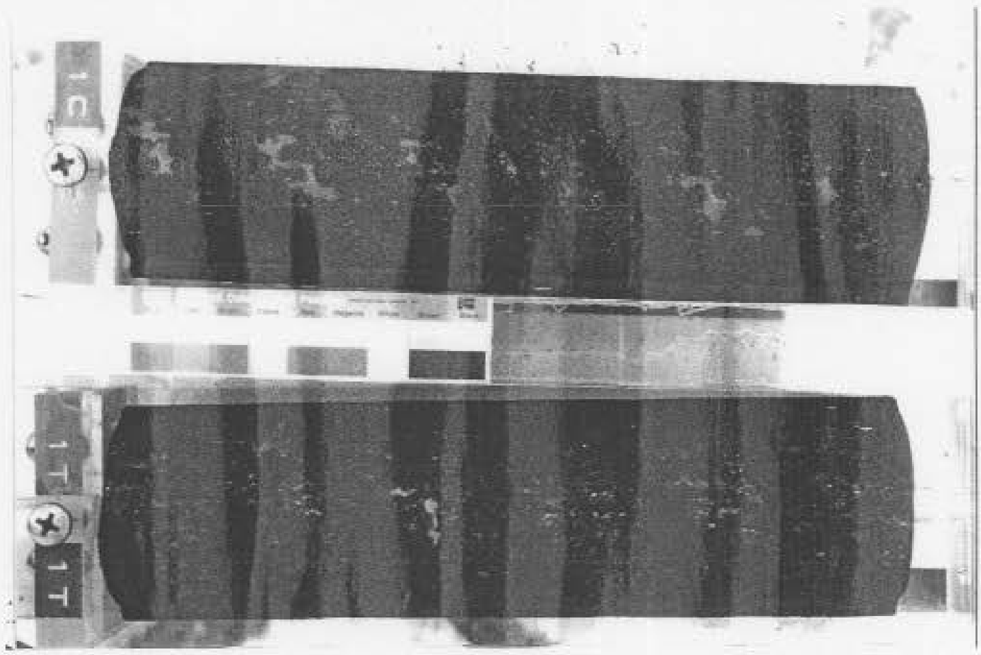

Plate 37 - Series 2, Group 1, Conventional(1C) and Tempcore (1T) Bars (taken on 24/6/94)

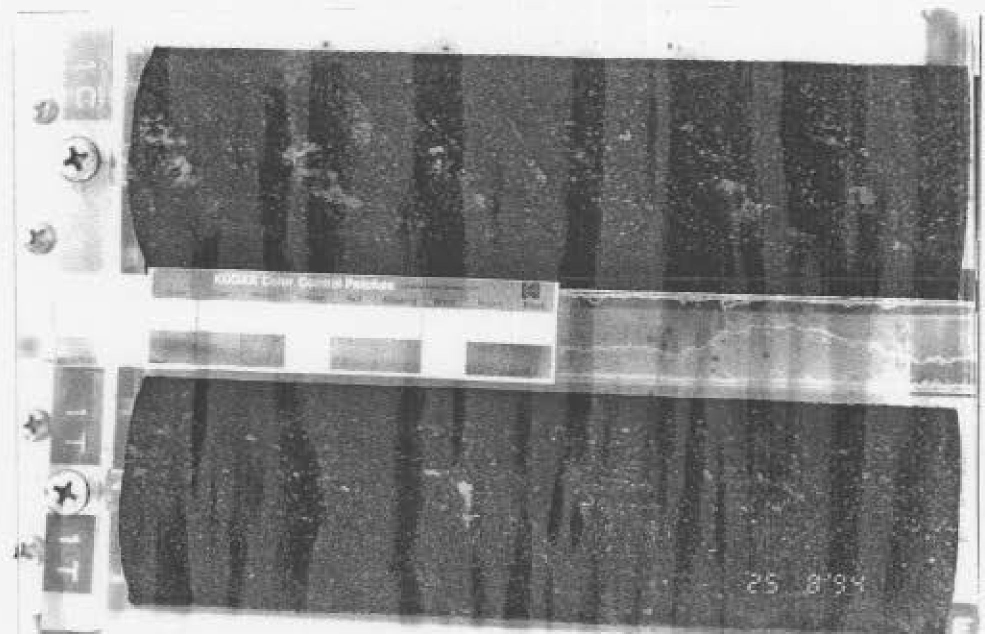

Plate 38 - Series 2, Group 1, Conventional(1C) and Tempcore(1T) Bars (taken on 25/8/94)

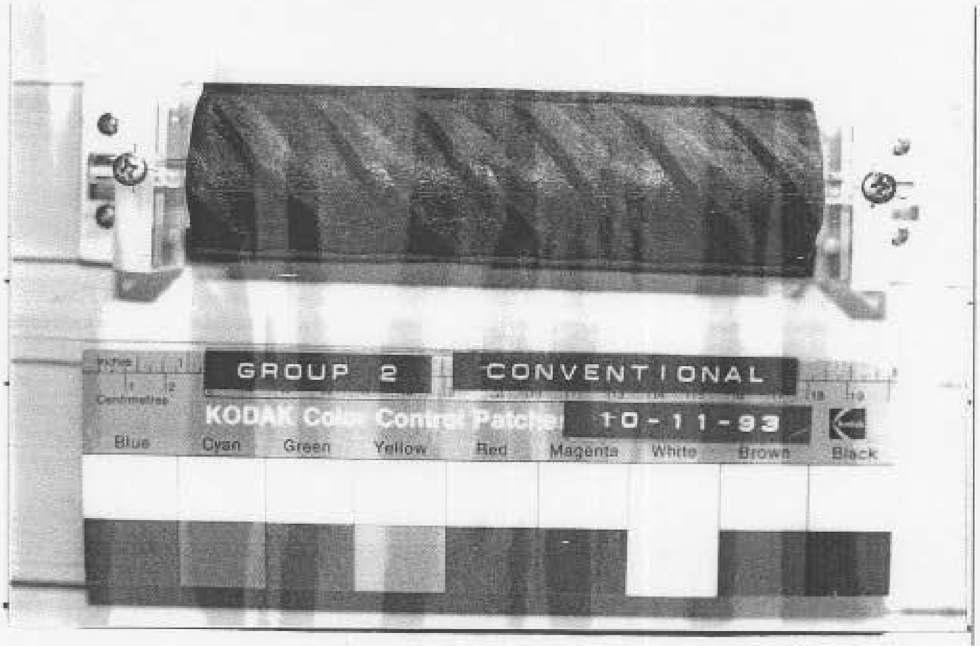

Plate 39 - Series 2, Group 2, Conventional Bar
(taken on 10/11/93)

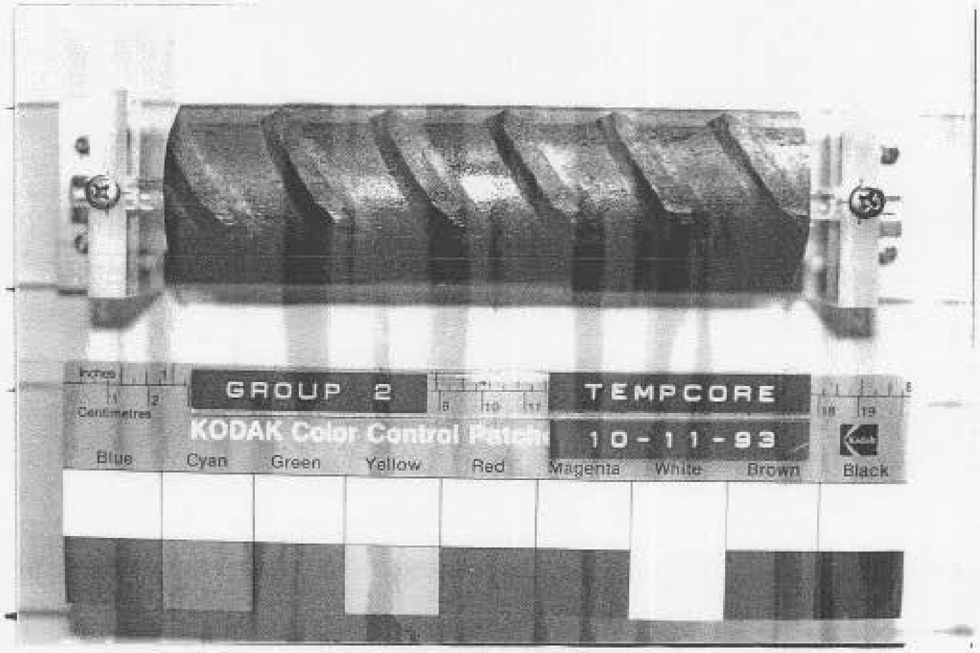

Plate 40 - Series 2, Group 2, Tempcore Bar
(taken on 10/11/93)

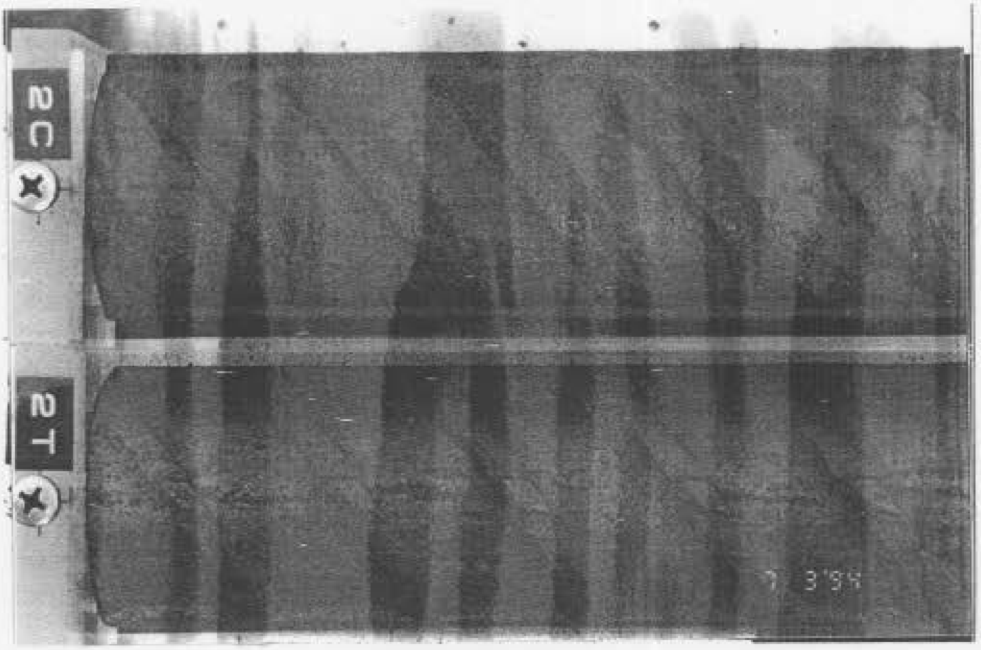

Plate 41 - Series 2, Group 2, Conventional(2C) and Tempcore(2T) Bars (taken on 7/3/94)

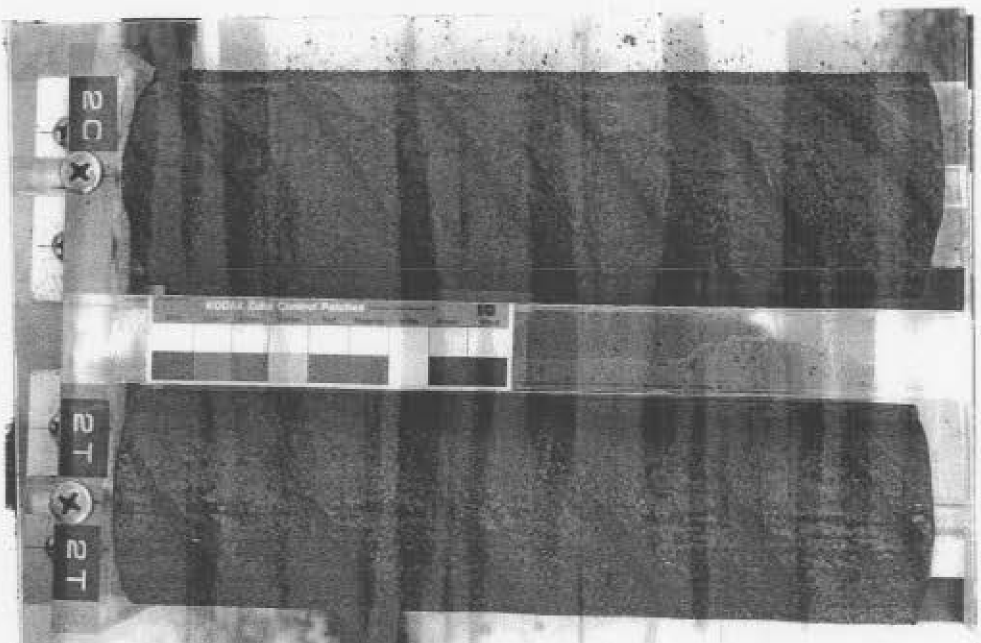

Plate 42 - Series 2, Group 2, Conventional(2C) and Tempcore(2T) Bars (taken on 24/6/94)

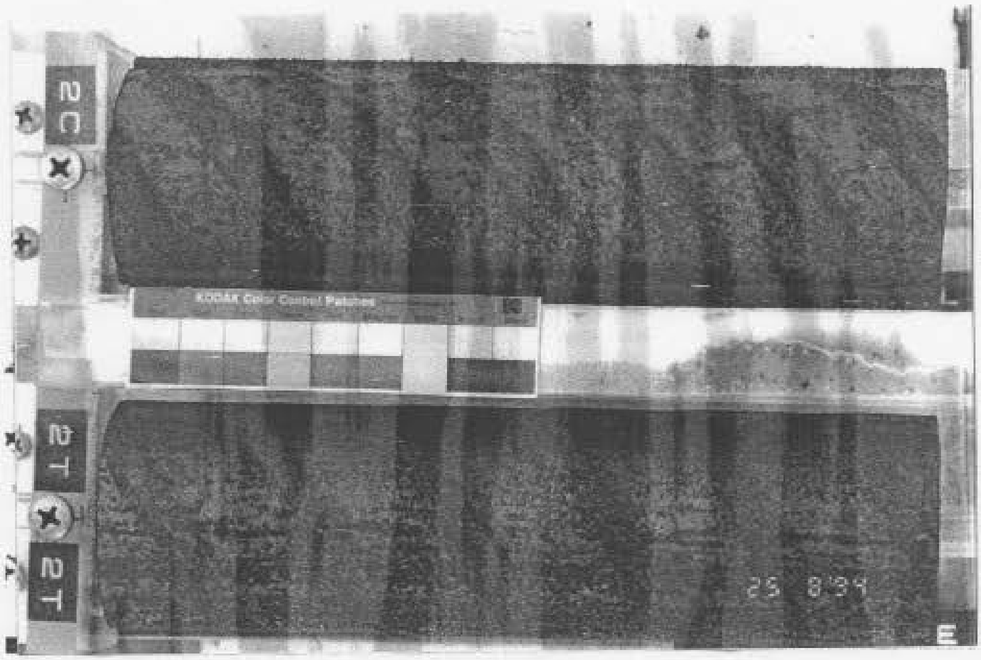

Plate 43 - Series 2, Group 2, Conventional(2C) and Tempcore(2T) Bars (taken on 25/8/94)

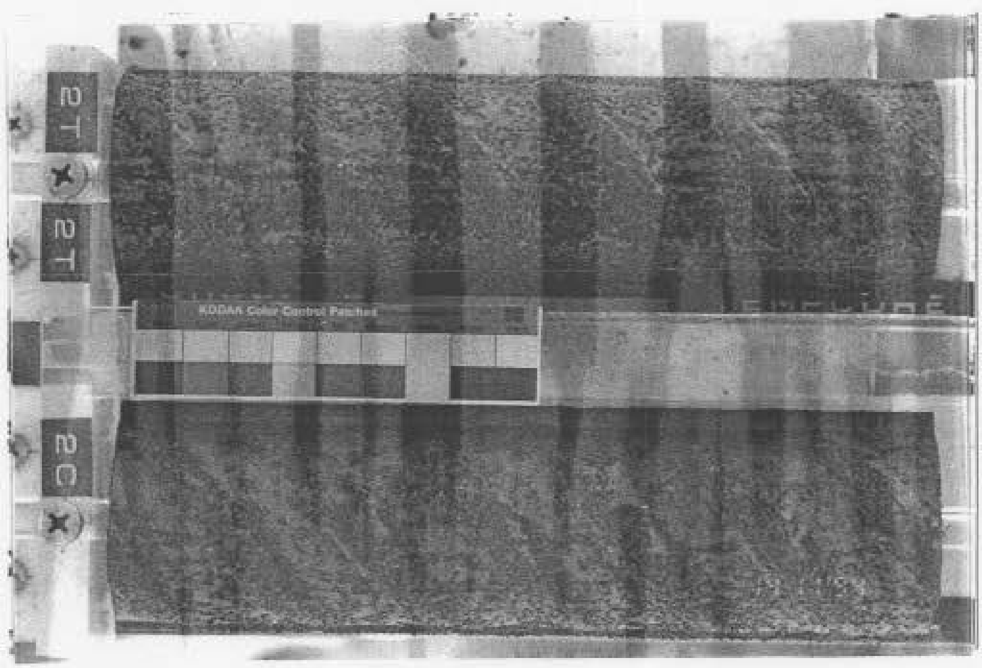

Plate 44 - Series 2, Group 2, Conventional(2C) and Tempcore(2T) Bars (taken on 14/11/94)

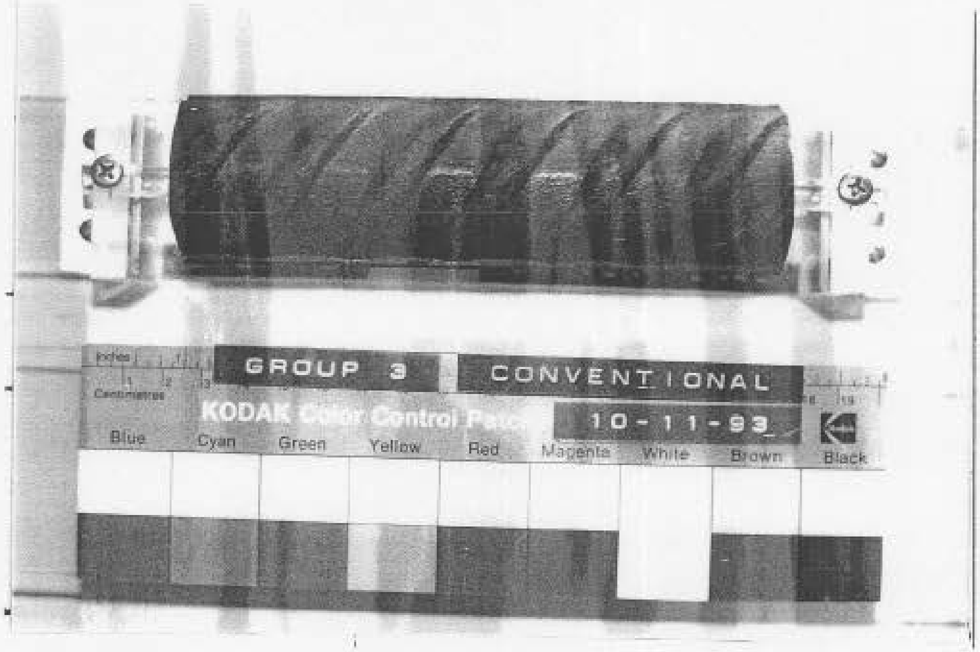

Plate 45 - Series 2, Group 3, Conventional Bar
(taken on 10/11/93)

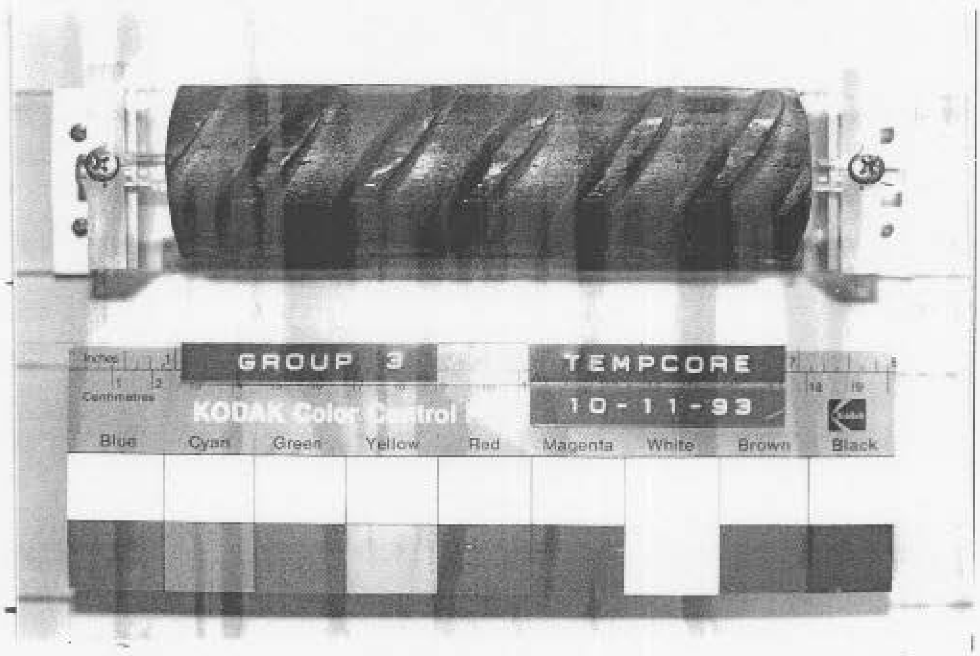

Plate 46 - Series 2, Group 3, Tempcore Bar
(taken on 10/11/93)

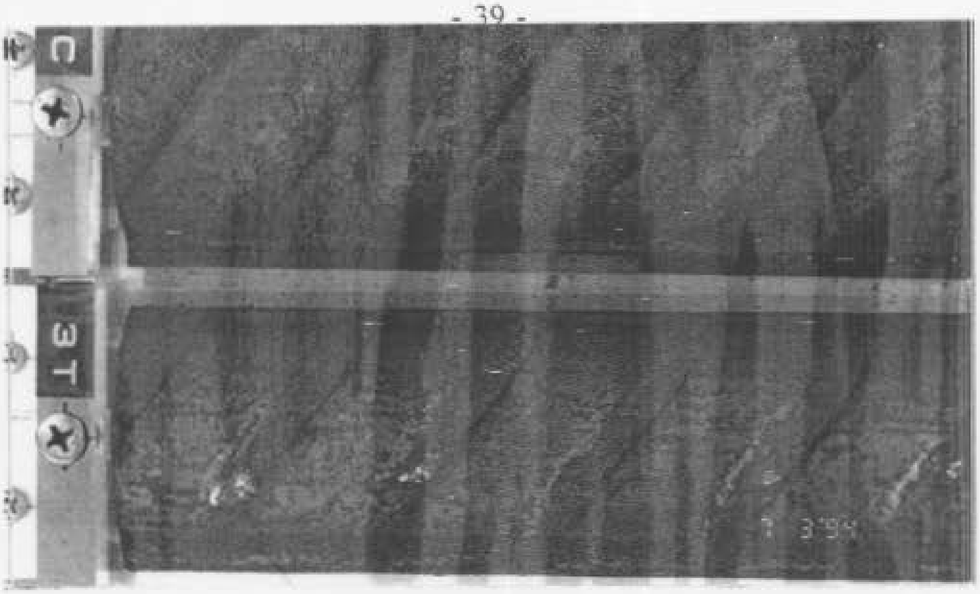

Plate 47 - Series 2, Group 3, Conventional(3C) and Tempcore(3T) Bars (taken on 7/3/94)

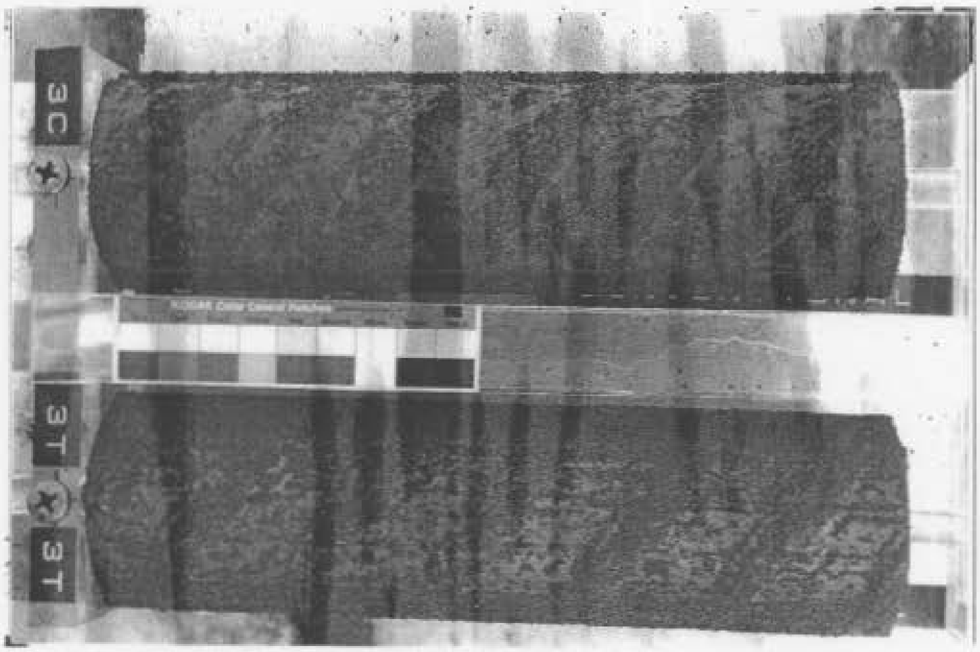

Plate 48 - Series 2, Group 3, Conventional(3C) and Tempcore(3T) Bars (taken on 24/6/94)

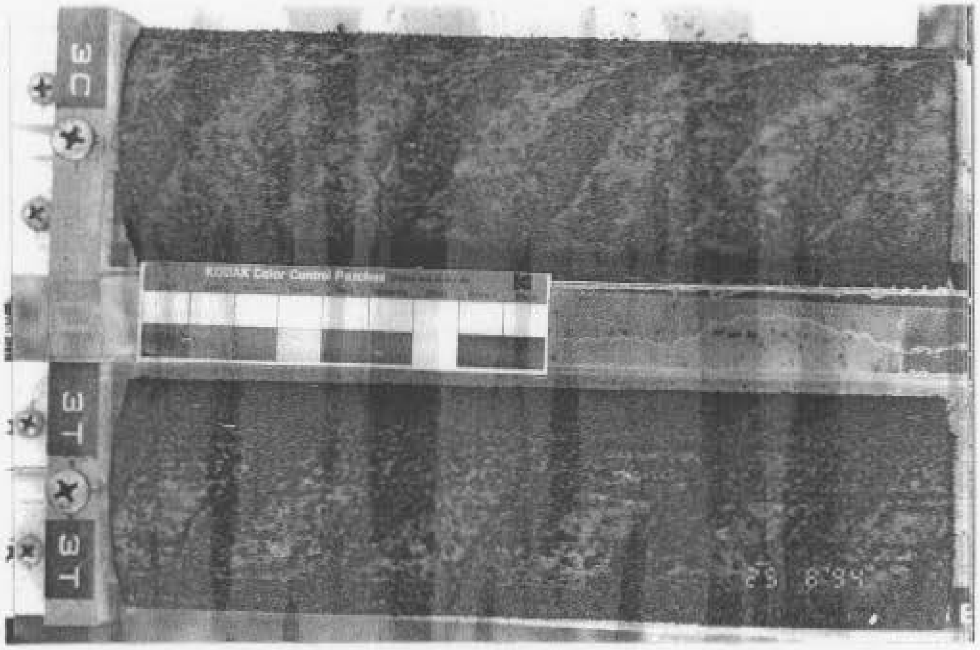

Plate 49 - Series 2, Group 3, Conventional(3C) and Tempcore(3T) Bars (taken on 25/8/94)

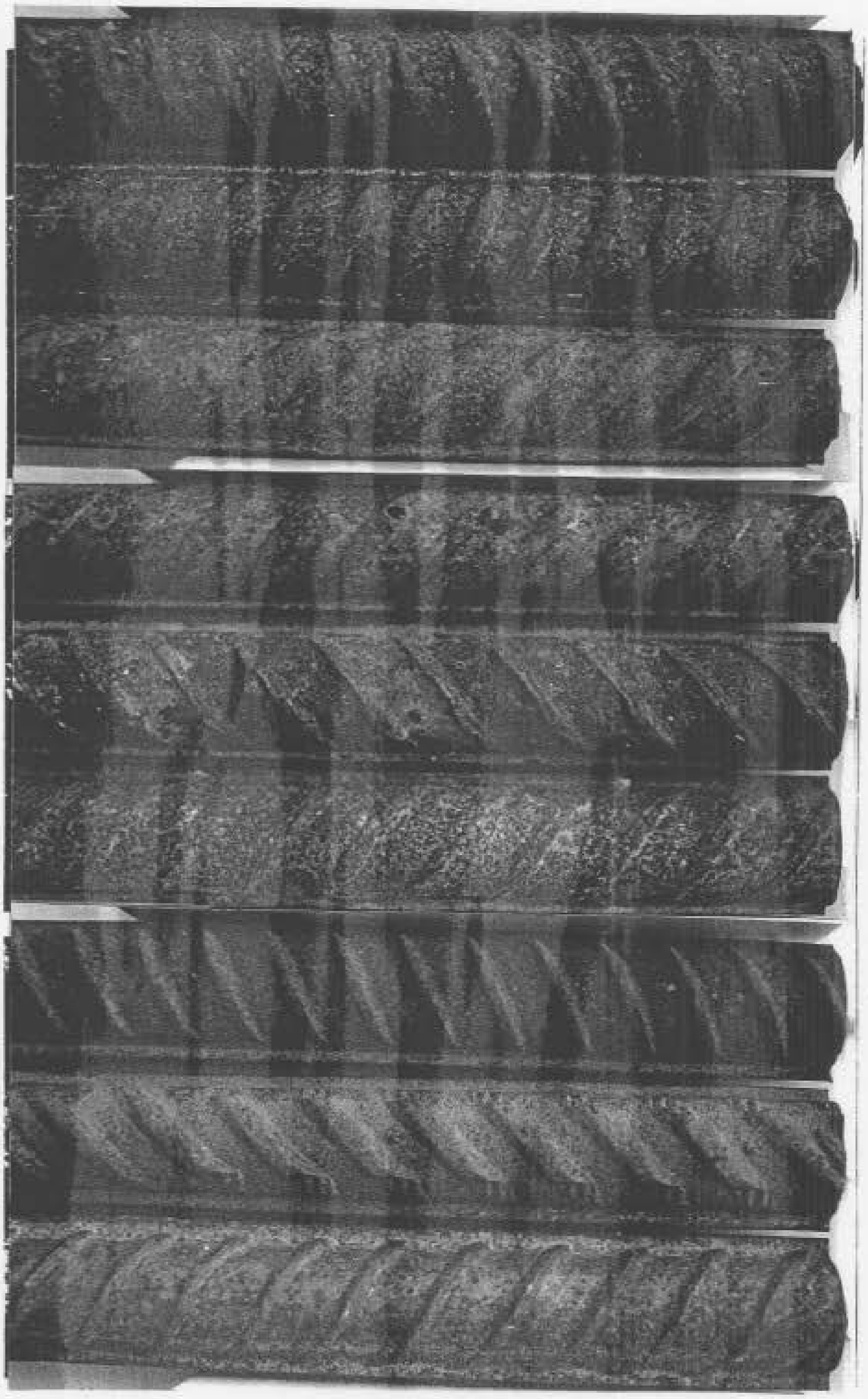

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Plate 50 - Rust Guide for Steel Reinforcement Bars
Nos. 1-6 : not acceptable: Nos. 7-18 : acceptable
(From App. 15-A. General Specification for Civil Engineering Works. Guidance Notes. 1992)

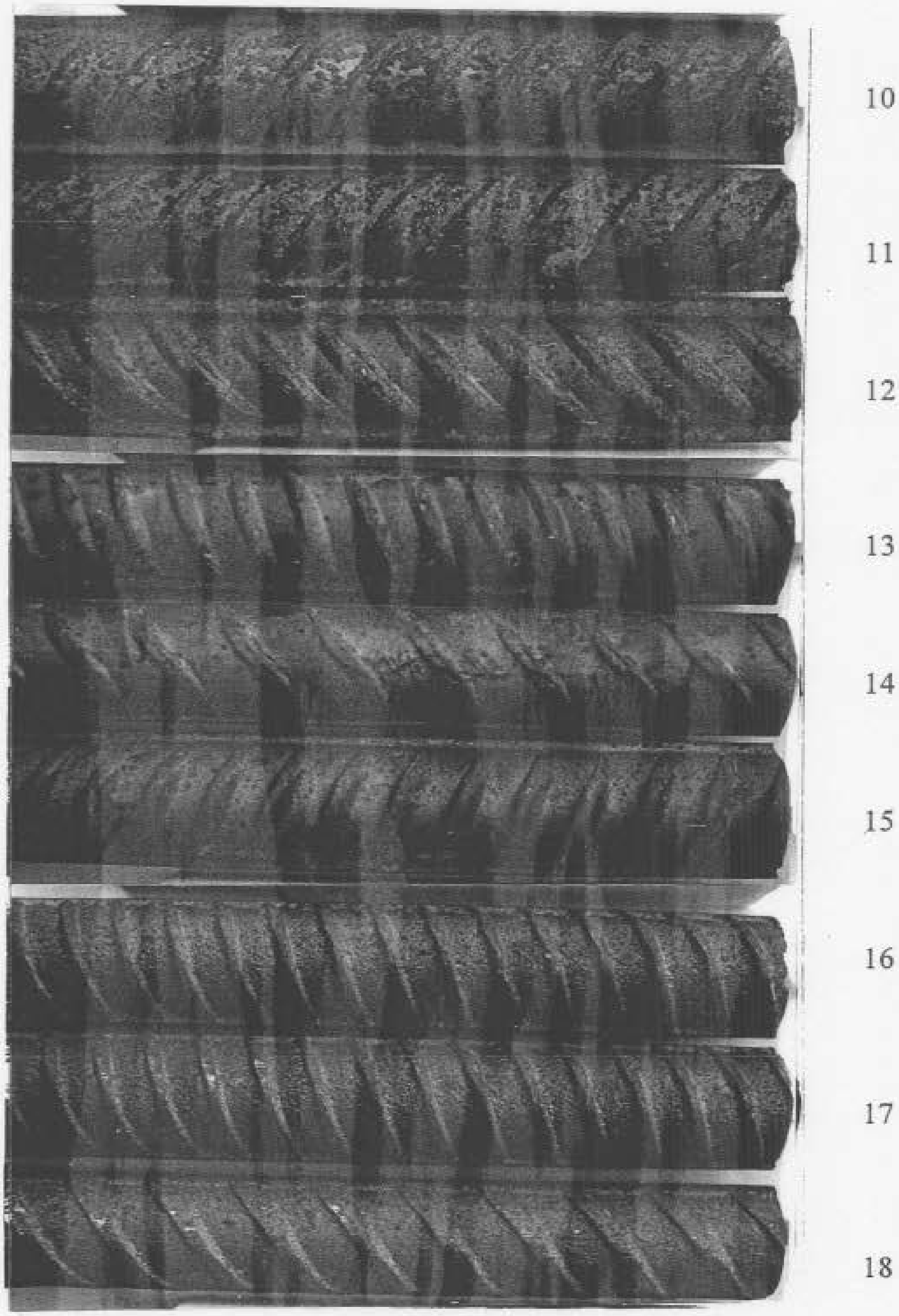

Plate 51 - Rust Guide for Steel Reinforcement Bars (Cont'd)
Nos. 1-6 : not acceptable; Nos. 7-18 : acceptable
(From App. 15-A, General Specification for Civil Engineering Works, Guidance Notes, 1992)

Appendix A

Project Brief on Investigation on the Surface Condition of
Steel Reinforcement Bars Produced by Conventional Process
Against Those Produced by "Tempcore" Process under Normal Exposure

→ GCM 4/2/13

4

MEMO

From Mr Philip Kwok, Secretary, SCCT
Sub-committee on Spec. for Reinft.

To CGE/Materials, CED

Ref. (58) in BLD(B) GR/CC/195

Tel. No. 848 1106

Your Ref. (3) in GCM 4/1C/5-7

Date 16 April 1993

dated 19.3.1993

GEOTECHNICAL ENGINEERING OFFICE
MATERIALS DIVISION
19 APR 1993
RECEIVED

Project Brief on Investigation on the Surface Condition of
Steel Reinforcement Bars Produced by Conventional Process
Against Those Produced by "Tempcore" Process under Normal Exposure

I refer to your captioned memo dated 19 March 1993. A project brief on the investigation exercise on the surface condition of steel reinforcement bars produced by different processes is outlined as follows:-

1. Objectives

To investigate and compare the surface condition of steel reinforcement bars produced by conventional process with those produced by "Tempcore" process under normal storage conditions before use in building works.

2. The Need

During the third sub-committee meeting of the Standing Committee on Concrete Technology (SCCT) Sub-committee on Specification for Reinforcement held on 20 January 1993, the stockists pointed out that steel bars produced by the "Tempcore" process rust faster than those produced by the conventional process and in some cases have been rejected because of their appearance. The sub-committee members were therefore interested to see the comparative effect of storage on these two types of bars to determine whether a problem exists. Hence the purpose of this exercise is to compare the surface condition for these two types of bars for a period of 12 months and record the appearance of the respective surface conditions.

3. Methodology

Observations on the comparative effects of exposure on steel reinforcement produced by the conventional and "Tempcore" process were set out as follows:

(i) 12 bar samples to be tested
3 samples of Tempcore rolling
3 samples of conventional rolling
(2 x 12 mm dia, 2 x 25 dia, 2 x 40 mm dia.)

(ii) bars to be stored at ambient temperature and humidity but sheltered from direct rain.

The Public Works Central Laboratory of the Materials Division of GEO will undertake the actions as outlined in paragraphs 3(ii) and (iii) and to produce a brief report on the observations.

5. Programme

No particular programme will be required as the procedure is to take photographs at monthly intervals. The report should be submitted to the SCCT at mid-April 1994.

6. Reviewers

The report will be submitted to the Chairman of the Works Branch Standing Committee on Concrete Technology for record and comment.

7. Consultation

Consultation with the Secretary of SCCT sub-committee on specification for reinforcement will be made in case of any anomaly with the observations.

8. Reporting

A report will be prepared for SCCT which may eventually be circulated to other Works Departments. It will contain:-

(i) monthly photographs for the reinforcement bars under investigation;
(ii) records of temperature and humidity of the reinforcement storage stack; and
(iii) observation and discussion.

9. Reference

Public Works Central Laboratory: SCCT - Rust Guide for Steel Reinforcement Bars (1992)

Philip Kwok
Secretary
Sub-committee on Specification for Reinforcement

SGE/L	SEC/L	SGE/SD	GE/		
	✓				