01 Jan 1997

Design of automotive structural components using high strength sheet steels mechanical properties of materials (aging effect)

Shaojie Wu

Chi-Ling Pan

Wei-wen Yu
Missouri University of Science and Technology, wwy4@mst.edu

Civil Engineering Study 97-1
Cold-Formed Steel Series

Twenty-First Progress Report

DESIGN OF AUTOMOTIVE STRUCTURAL COMPONENTS USING HIGH STRENGTH SHEET STEELS

MECHANICAL PROPERTIES OF MATERIALS (Aging Effect)

By

Shaojie Wu
Research Associate

Chi-Ling Pan
Consultant
Chaoyang University of Technology

Wei-Wen Yu
Project Director

A Research Project Sponsored by the American Iron and Steel Institute

January, 1997

Department of Civil Engineering
University of Missouri-Rolla
Rolla, Missouri

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

It has been known for years that mechanical properties of thin sheet steels, such as yield strength, tensile strength, and ductility, are affected by aging (Chajes et al. 1963, Hertzberg 1989, Yu 1991). The aging effect on mechanical properties can be described as follows. For a virgin steel that is initially loaded in tension beyond its yield strength and into strain hardening state and then unloaded to zero stress, the yield and tensile strengths of the steel increase while the ductility of the steel decreases if the steel is reloaded in tension again after a period of time from the first unloading. Due to diffusion of the carbon and nitrogen in steels and the fact that steel sheets are usually produced in a cold rolling process, in which the sheet steels undergo large plastic deformation, their mechanical properties can be affected by aging. Therefore, the mechanical properties of the thin sheet steels at the time when they are used can be different from the properties at the time when they are produced. The yield and tensile strengths of the sheet steels will increase over time while the ductility of the steels will decrease.

In 1992, a research project, sponsored by the American Iron and Steel Institute (AISI), was carried out at the University of Missouri-Rolla to study the effect of strain rate on the mechanical properties of sheet steels (Pan and Yu 1992). In this research, coupons cut from two selected sheet steels (25AK and 50SK) were tested in longitudinal and transverse tension and compression at four different strain rates, namely 0.0001, 0.01, 0.1, and 1.0 in./in./sec.. The results of the study were reported by Pan and Yu (1992). Later on for another study on the strength of hybrid structural components made of these two steels (Pan and Yu 1995), the mechanical properties of the steels that were obtained in 1992 were used to evaluate the strength of the hybrid members without consideration of the aging effect. In this later study, the hybrid members were tested in bending at the strain rates of 0.0001 and 0.01 in./in./sec..

In order to estimate the aging effect on the mechanical properties of two types of sheet steels used by Pan and Yu (1992), additional coupon tests of the sheet steels (25AK and 50SK) were conducted at the University of Missouri-Rolla in August 1995 and in January 1997. A total of twenty coupons, ten for each steel, were tested at two different strain rates, namely 0.0001 and 0.01 in./in./sec.. Four coupons for each steel were tested at the strain rate of 0.0001 in./in./sec. in August 1995, while three coupons for each steel were tested at the strain rate of 0.0001 in./in./sec. in January 1997 and another three coupons for each steel were tested at the strain rate of 0.01 in./in./sec. at the same time. This report summarizes the results of the twenty coupon tests. In the following discussions, Section 2 presents the test results on the mechanical properties of 25AK and 50SK sheet steels. Section 3 compares the mechanical properties of the steels reported by Pan and Yu (1992) with those presented in Section 2 to estimate the aging effect on steels and the computed yield moments. Finally, Section 4 summarizes the findings.

2. COUPON TESTS OF 25AK AND 50SK SHEET STEELS

This section summarizes the test results for the coupons cut from the 25AK and the 50SK sheet steels. Section 2.1 describes preparation of the test coupons. Section 2.2 deals with the test procedure. Section 2.3 presents the test results.

2.1 Preparation of Test Coupons

Twenty rectangular steel plates with approximately 2-1/8"x10-1/4"x0.0078 in dimension were cut from the top flanges of the hybrid beams tested earlier by Pan and Yu (1995). These tested hybrid beams were marked as 3C1AK, 3C1AS, 3C1AZ, 3C2AK, 3C2AS, 3C3AK, 3C3AZ, and 3C3BK. The designation of beam specimens is given in Table 2.1.1. These beams were fabricated from two different sheet steels (25AK and 50SK steels) as shown in Fig. 2.1.1. The steel plates were cut from the ends of the tested beams. Since the beams were simply supported when tested, the sheets located at the top flanges at the ends of the beams behaved elastically when the beams were tested. Therefore, the mechanical properties of the sheet steels cut from the tested beams are considered to be not affected by the beam tests.

The twenty steel plates were then machined to form standard tension coupons according to the ASTM A370 and E8 as shown in Fig. 2.1.2. A metal scriber with fine pointer was used to mark 2-inch gage lines on the narrow strip of the coupons. The width of the strip was then measured at three locations, with two at the two gage lines and one at the center of the strip. The three width values were averaged for each coupon and the average widths are listed in Tables 2.1.2, 2.1.3, and 2.1.4. The thicknesses of the two steel sheets were also measured and listed in Tables 2.1.2, 2.1.3, and 2.1.4.

The designation used for the coupons as shown in these tables is described as follows. For "25AK-1-95s", "25AK" indicates that the coupon was made of 25AK steel; "-1" represents the first test; and "-95s" indicates that the coupon was tested at the strain rate of 0.0001 in./in./sec. (slow mode) in August 1995. For "50SK-2-97f", "50SK" indicates that the coupon was made of 50SK steel; "-2" represents the second test; and "-97f" indicates that the coupon was tested at the strain rate of 0.01 in./in./sec. (fast mode) in January 1997.

2.2 Test Procedure

The MTS Test System located at the Engineering Research Laboratory of the University of Missouri-Rolla was used to carry out the coupon tests. The System consists of a loading frame with top and bottom grips, various control panels, and a data acquisition system with a real time computer monitor. The System uses the close-loop control scheme with three main control modes, namely load, strain, and displacement controls which are automatically operated in the System (including the grip hydraulic system).

Prior to coupon tests, a trial-and-error process was carried out to achieve the strain rate of 0.0001 and 0.01 in./in./sec. through the displacement control mode. For each coupon test, the displacement control mode was first used to set up the net distance between the two grips. A coupon was first placed and gripped in the lower grip while the alignment of the coupon on both upper and lower grips was undertaken. An MTS 2-inch gage length extensometer with a 50% strain measuring capacity was placed in the middle of the coupon. The two knife edges of the extensometer were aligned at the two scribed line markers 2-inch apart. Prior to tightening the upper grip, the force, strain, and displacement conditioners were zeroed. The upper grip was then tightened. The data acquisition system was switched to collect data immediately when the test was started. The entire test process was controlled under the displacement mode so that an unloading branch in the stress-strain relationship can be obtained.

2.3 Test Results

At the Strain Rate of 0.0001 In./In./Sec.

Fourteen coupons (25AK-1-95s through 25AK-4-95s, 50SK-1-95s through 50SK-4-95s, 25AK-1-97s through 25AK-3-97s, and 50SK-1-97s through 50SK-3-97s) were tested at the strain rate of 0.0001 in./in./sec.. The test results, including yield strength, tensile strength, and percent elongation in a 2-inch gage length, are presented in Tables 2.1.2 and 2.1.4.

Typical stress-strain relationships of steels are illustrated in Figures 2.3.1 through 2.3.4.

Figures 2.3.1 and 2.3.3 show that the stress-strain relationship of the 25AK steel is of a gradual yielding type, while the stress-strain relationship of the 50SK steel is of a sharp yielding type. The shapes of the stress-strain curves of both 25AK and 50SK steels tested in August 1995 and January 1997 are similar to those obtained by Pan and Yu in March 1992 (1992) as shown in Figures 2.3.5 and Figure 2.3.6. It was noted in the tests that both steels were ductile since necking in the coupons prior to the fracture was clear. All the coupons fractured in the middle of the narrow strip.

Table 2.1.2 presents the results for the coupons tested at the strain rate of 0.0001 in./in./sec.. in January 1997. In this table, the yield strength of the 25AK steel ranges from 25.2 to 26.8 ksi with a mean value of 26.0 ksi. The tensile strength of the same steel ranges from 44.6 to 45.1 ksi with a mean value of 44.8 ksi. The elongation in a 2-inch gage length of the steel ranges from 41.50 to 42.67% with a mean value of 42.19%. The results for the 25AK coupons tested in August 1995 at the same strain rate are similar to the results obtained in January 1997 as shown in Table 2.1.4.

The yield and tensile strengths of the 50SK steel tested at the strain rate of 0.0001 in./in./sec. in January 1997 are also presented in Table 2.1.2. The yielding strength of the 50SK steel ranges from 56.4 to 59.8 ksi with a mean value of 57.7 ksi. The tensile strength of the steel ranges from 69.1 to 70.3 ksi with a mean value of 69.6 ksi. The elongation in a 2-inch gage length of the steel is smaller than that of the 25AK steel and ranges from 31.25 to 32.64% with a mean value of 31.84%. The coupons of the 50SK steel tested in August 1995 at the same strain rate illustrate the similar results as shown in Table 2.1.4.

At the Strain Rate of 0.01 In./In./Sec.

Six coupons (25AK-1-97f through 25AK-3-97f and 50SK-1-97f through 50SK-3-97f) were tested at the strain rate of 0.01 in./in./sec. in January 1997. The test results also include the yield strength, tensile strength, and percent elongation in a 2-inch gage length as presented in Tables 2.1.3. Typical stress-strain relationships of the 25AK and 50SK steels are illustrated in Figures 2.3.7 and 2.3.8, respectively.

The shapes of the stress-strain relationship of the 25AK and 50SK steels tested in the faster strain rate (0.01 in./in./sec.) in January 1997 are similar to those tested in the slower strain rate (0.0001 in./in./sec.) in January 1997 and those tested in the faster strain rate (0.01 in./in./sec.) by Pan and Yu in March 1992 (1992) as shown in Figures 2.3.5 and 2.3.6, where the 25AK steel shows the gradual yielding type while the 50SK steel shows the sharp yielding type. All the coupons failed in a ductile mode and fractured in the middle portion of the narrow strip of the coupons within the two gage lines of the extensometer.

As indicated in Table 2.1.3, the yield strength of the 25AK steel ranges from 29.8 to 31.2 ksi with a mean value of 30.5 ksi. The tensile strength of the steel ranges from 48.5 to 49.1 ksi with a mean value of 48.8 ksi. The elongation in 2-inch gage length ranges from 43.88 to 45.48% with a mean value of 44.83%. For the 50SK steel, the yield strength ranges from 60.7 to 61.2 ksi with a mean value of 61.0 ksi. The tensile strength ranges from 70.5 to 72.1 ksi with a mean value of 71.4 ksi. The elongation in 2-inch gage length ranges from 25.80 to 29.91% with a mean value of 27.85%.

3. COMPARISONS OF MECHANICAL PROPERTIES AND YIELD MOMENTS OF HYBRID BEAMS AS AFFECTED BY AGING

3.1 Mechanical Properties of Sheet Steels

This part of the report compares the mechanical properties of the 25AK and 50SK sheet steels reported in Section 2 with those reported by Pan and Yu (1992) to determine the changes on the mechanical properties of the steels due to the effect of aging. The mechanical properties of the steels for the strain rate of 0.0001 in./in./sec. will be compared first, followed by the comparison of mechanical properties for the strain rate of 0.01 in./in./sec..

<u>At the Strain Rate of 0.0001 In./In./Sec.</u>

The mean values of the yield strength, tensile strength, and elongation in a 2-inch gage length of the 25AK and 50SK steels, which were tested at the strain rate of 0.0001 in./in./sec. in January 1997, are listed in Table 2.1.2. Also included in the same table are the mean values of the yield and tensile strengths and the elongation in a 2-inch gage length of the steels tested by Pan and Yu (1992). Since coupon tests reported by Pan and Yu were conducted in March 1992, the aging effect can be considered for four years and ten months between these two testing programs.

The ratios of the mean values reported in Table 2.1.2 to those reported by Pan and Yu are calculated and listed in Table 3.1. The ratio of the mean yield strength obtained in 1997 to that obtained in 1992 is 1.06 for the 25AK steel and 1.05 for the 50SK steel. The ratio of the mean tensile strength obtained in 1997 to that obtained in 1992 is 1.05 for the 25AK steel and 1.04 for the 50SK steel. The increases in the yield strength due to aging effect are approximately the same as the increases in the tensile strength. The increases in both yield and tensile strengths of the 50SK steel appear to be slightly lower than the increases in the strengths of the 25AK steel. This indicates that aging may have slightly less effect on the 50SK steel than on the 25AK steel. The elongation in 2-inch gage length of the 50SK steel obtained in January 1997 is smaller than that obtained in March 1992.

<u>At the Strain Rate of 0.01 In./In./Sec.</u>

The mean values of the yield strength, tensile strength, and elongation in a 2-inch gage length of the 25AK and 50SK steels tested at the strain rate of 0.01 in./in./sec. in January 1997 are listed in Table 2.1.3. In the same table, the mean values of the yield and tensile strengths and the elongation in a 2-inch gage length of the steels tested by Pan and Yu in March 1992 (1992) are listed in the parentheses.

The ratios of the mean strengths reported in Table 2.1.3 to those reported by Pan and Yu are calculated and listed in Table 3.1. The ratio of the mean yield strength obtained in 1997 to that obtained in 1992 is 1.10 for the 25AK steel and 1.07 for the 50SK steel. The ratio of the mean tensile strength obtained in 1997 to that obtained in 1992 is 1.10 for the 25AK steel and 1.04 for the 50SK steel. Similar to the situation at the lower strain rate, the increases in the yield strength at the higher strain rate due to the aging effect are approximately the same as the increases in the tensile strength. The increase of both yield and tensile strengths in the 50SK steel are slightly lower than the increase of the strengths in the 25AK steel. This again indicates that the aging may have slightly less effect on the 50SK steel than on the 25AK steel. The elongation in a 2-inch gage length of the steels obtained in January 1997 is smaller than that obtained in March 1992.

Finally, Table 3.1 lists the ratios of the mean yield strength, tensile strength, and elongation in a 2-inch gage length obtained at the strain rate of 0.0001 in./in./sec. to those obtained at the strain rate of 0.01 in./in./sec. The strength ratios obtained in January 1997 are slightly higher than those obtained in March 1992, while the elongation ratio of the 50SK steel obtained in January 1997 is smaller than that obtained in March 1992. This indicates that the aging may have slightly more effect on material properties at faster strain rate, resulting in a further increase of strength and reduction of ductility.

Figures 3.1 and 3.2 compare the stress-strain relationships of the 25AK and 50SK steels tested at the two different strain rates in January 1997. It is noted that at the faster strain rate (0.01 in./in./sec.), the increase of both yield and tensile strengths of the 25AK steel is slightly higher than the increase of the strengths in the 50SK steel. This trend can also be seen in Table 3.1 for the tests conducted in 1992. At the faster strain rate, the yield strength of the steels tends to increase slightly more than the tensile strength of the steels.

Figures 3.3 and 3.4 show the variation of the average yield and tensile strengths of the 25AK steel over the time period of 58 months at the strain rates of 0.0001 in./in./sec. and 0.01 in./in./sec., respectively. For the coupons tested at the strain rate of 0.0001 in./in./sec., the average yield and tensile strengths of the steel tend to increase slightly over time, but the rate of the strength increase also decreases with the time. For the coupons tested at the strain rate of 0.01 in./in./sec., the average yield and tensile strengths of the steel similarly tend to increases with time. The rate of the strength increase over time at the faster strain rate can not be obtained due to only two data points in each figure.

Figures 3.5 and 3.6 show the variation of the average yield and tensile strengths of the 50SK steel over the time period of 58 months at the strain rates of 0.0001 in./in./sec. and 0.01 in./in./sec., respectively. The similar trends as seen with the 25AK steel can be seen with the 50SK steel from the figures.

3.2 Yield Moments of Hybrid Beams

In Chapter 1 of this report, it was mentioned that the mechanical properties of 25AK and

50SK sheet steels obtained in March 1992 were used to calculate the strength of the hybrid beams which were tested in February 1994 without considering the aging effect on material properties. In order to study the changes of the computed yield moments as affected by the changes of the yield stress of steel due to aging effect, the yield moments of six hybrid beams were recomputed by using the dynamic tensile yield stresses interpolated from Figures 3.3 and 3.5 for the time of beam tests. These recomputed yield moments, $(M'_y)_{comp}$, are presented in Table 3.2 of this report together with the original values of $(M_y)_{comp}$ obtained from Tables 4.10, 4.11, and 4.12 of the 20th Progress Report. Also included in Table 3.2 are the dynamic tensile yielded stresses used for the recalculations of yield moments.

For the purpose of evaluating the differences between the originally computed yield moments and the recomputed yield moments, Table 3.3 of this report lists the tested yield moments, $(M_y)_{test}$; the computed yield moments, $(M_y)_{comp}$; the recomputed yield moment, $(M'_y)_{comp}$; and the ratios of $(M_y)_{test}/(M_y)_{comp}$ and $(M_y)_{test}/(M'_y)_{comp}$. The tested yield moments were determined from the tested yield load (P_y), which was obtained from the load-strain relationship of the test specimen when the measured strain of the extreme fiber reached to yield strain.

From Tables 3.2 and 3.3, it can be seen that even though the dynamic tensile yield stress of 25AK steel increased from 4.1% to 5.4% and the dynamic tensile yield stress of 50SK steel increased from 2.9% to 3.5% during the period of 23 months, the ratio of the tested-to-computed yield moments was affected only from 2.2% to 4.3% as indicated in Column (6) of Table 3.3. Similar comparisons can also be made for other cases. The reason for the less aging effect on the yield moment than the material properties of steel is due to the fact that the yield moment depends not only on the yield point of steel, but also on the strain rate, the stress-strain relationship of the steel (sharp-yielding or gradual-yielding), the proportional limit and yield strain of steel, the composition and configuration of the cross section, the width-to-the thickness ratio of the compression flange, and the stresses developed in the entire section. Therefore, it can be concluded that the aging effect on the bending capacity of hybrid beams is slightly less than the aging effect on material properties of steel.

4. SUMMARY

Based on the results presented in Sections 2 and 3, the findings are summarized as follows:

1. At the strain rate of 0.0001 in./in./sec., the yield and tensile strengths of the 25AK and 50SK steels that were tested in January 1997 increased by 4 to 6% as compared to those obtained by Pan and Yu (1992) over a time period of four years and ten months due to the effect of aging. The percent elongation in a 2-inch gage length of the 50SK steel decreased by 12% as compared with that obtained by Pan and Yu (1992).

2. At the strain rate of 0.01 in./in./sec., the yield and tensile strengths of the 25AK and 50SK steels that were tested in January 1997 increased by 4 to 10% as compared to those obtained by Pan and Yu (1992) over a time period of four years and ten months due to the effect of aging. The percent elongation in a 2-inch gage length decreased by 9% for the 25AK steel and 16% for the 50SK steel as compared with those obtained by Pan and Yu (1992).

3. The percentage increases in the yield strength of the 25AK and 50SK steels are approximately the same as the percentage increases in the tensile strength of both steels over the period of four years and ten months.

4. The increases in both yield and tensile strengths of the 25AK steel appear to be slightly higher than the increases in the strengths of the 50SK steel over the period of four years and

ten months. The 25AK steel is a relatively lower strength steel as compared with the 50SK steel (refer to Tables 2.1.2 and 2.1.3).

5. The aging appears to have slightly more effect on the yield and tensile strengths of the 25AK and 50SK steels at the faster strain rate of 0.01 in./in./sec. as compared to the strain rate of 0.0001 in./in./sec..

6. Strain rate tends to have slightly more effect on the yield strength of the 50SK steel than on the tensile strength of the 50SK steel.

7. It appears that the changes in the mechanical properties of the 25AK and 50SK steels due to the aging effect decrease over time.

8. The aging effect on the bending capacities of the hybrid beams compared in this report was found to be slightly less than the aging effect on material properties of steel. Similar comparisons can also be made for the other cases.

ACKNOWLEDGEMENTS

The research work reported herein was conducted in the Department of Civil Engineering at the University of Missouri-Rolla under the sponsorship of the American Iron and Steel Institute.

The financial assistance granted by the Institute and the technical guidance provided by members of the AISI Task Force on Automotive Structural Design of the AISI Automotive Applications Committee and the AISI staff (S.J. Errera, D.C. Martin, and L.A. Rysdrop) are gratefully acknowledged. Presently, members of the Task Force are: Messrs. E. C. Oren (Chairman), G. A. Beecher, J. Borchelt, T. Khalil, R.W. Lautensleger, H. F. Mahmood, D. Malen, M.Y. Sheh, and M.T. Vecchio. Former members of the Task Force included Messrs. C. Haddad, C.M. Kim, J. G. Schroth, and T. N. Seel.

All materials used in the experimental study were donated by Inland Steel Company and National Steel Corporation.

Appreciation is expressed to J. Bradshaw, J. McCracken, and S. Gabel, staff of the Department of Civil Engineering, for their technical support.

REFERENCES

ASTM A370, "Standard Methods and Definitions for Mechanical Testing of Steel Products," Annual Book of ASTM Standards, 1995.

ASTM E8, "Tension Testing of Metallic Materials," Annual Book of ASTM Standards, 1996.

Chajes, A., Britvec, S.J., and Winter, G. (1963) "Effects of Cold-Straining on Structural Sheet Steels," Journal of the Structural Division, ASCE Proceedings, Vol. 89, April.

Hertzberg, R.W. (1989) "Deformation And Fracture Mechanics of Engineering Materials," Third Edition, John Wiley & Sons, Inc.

Pan, C.L. and Yu, W.W. (1992) "Design of Automotive Structural Components Using High Strength Sheet Steels: Mechanical Properties of Materials," Civil Engineering Study 92-2, Cold-Formed Steel Series, Seventeenth Progress Report, Department of Civil Engineering, University of Missouri-Rolla, May.

Pan, C.L. and Yu, W.W. (1995) "Design of Automotive Structural Components Using High Strength Sheet Steels: Effect of Strain Rate on the Structural Strength of Cold-Formed Steel Hybrid Beams," Civil Engineering Study 95-4, Cold-Formed Steel Series, Twentieth Progress Report, Department of Civil Engineering, University of Missouri-Rolla, June.

Yu, W.W. (1991) "Cold-Formed Steel Design," Second Edition, John-Wiley & Sons. Inc.

Table 2.1.1 Designation of Beam Specimens Used in This Study (Pan and Yu, 1995)

1st Digit	1st Letter	2nd Digit	2nd Letter	3rd Letter
Test Type	w/t Ratio (Case)	Strain-Rate (in./in./sec.)	Test No.	Section Type (Group)
3: Beam Test	A: Small B: Medium C: Large	1: 0.0001 2: 0.001 3: 0.01	A: 1st Test B: 2nd Test	W: Hat Sec. -25AK Plate -50SK Z: Hat Sec. -25AK Plate -50SK S: Hat Sec. -50SK Plate -25AK K: Hat Sec. -50SK Plate -25AK

Note:

(1) For the specimens with the section types of "W" or "S", the stiffened plate is tested on the tension side.

(2) For the specimens with section types of "Z" or "K", the stiffened plate is tested on the compression side.

(3) See Figure 2.1.1.

Table 2.1.2 Mechanical Properties of 25AK and 50SK Sheet Steels in Longitudinal Tension at the Strain Rate of 0.0001 in./in./sec., Obtained in January 1997

Specimens	Thickness of Coupon (in.)	Average Width of Coupon (in.)	Strain Rate (in./in./sec.)	Yield Strength F_y (ksi)	Tensile Strength F_u (ksi)	Elongation in 2-inch Gage Length (%)
25AK-1-97s	0.079	0.503	0.0001	26.8	45.1	42.67
25AK-2-97s	0.079	0.498	0.0001	25.2	44.6	41.50
25AK-3-97s	0.079	0.499	0.0001	26.0	44.7	42.41
Average	0.079	0.500	0.0001	26.0 (24.6)	44.8 (42.8)	42.19 (N/A)
50SK-1-97s	0.078	0.505	0.0001	56.4	69.1	31.25
50SK-2-97s	0.078	0.503	0.0001	59.8	70.3	32.64
50SK-3-97s	0.078	0.503	0.0001	56.8	69.4	31.64
Average	0.078	0.504	0.0001	57.7 (55.0)	69.6 (67.1)	31.84 (36.09)

Note: The data in parentheses are the average mechanical properties obtained by Pan and Yu in March 1992 (1992).

Table 2.1.3 Mechanical Properties of 25AK and 50SK Sheet Steels in Longitudinal Tension at the Strain Rate of 0.01 in./in./sec., Obtained in January 1997

Specimens	Thickness of Coupon (in.)	Average Width of Coupon (in.)	Strain Rate (in./in./sec.)	Yield Strength F_y (ksi)	Tensile Strength F_u (ksi)	Elongation in 2-inch Gage Length (%)
25AK-1-97f	0.079	0.502	0.01	29.8	48.5	45.12
25AK-2-97f	0.079	0.504	0.01	31.2	48.9	45.48
25AK-3-97f	0.079	0.503	0.01	30.5	49.1	43.88
Average	0.079	0.503	0.01	30.5 (27.9)	48.8 (44.4)	44.83 (49.31)
50SK-1-97f	0.078	0.498	0.01	60.7	70.5	25.80
50SK-2-97f	0.078	0.499	0.01	61.0	72.1	27.83
50SK-3-97f	0.078	0.503	0.01	61.2	71.6	29.91
Average	0.078	0.500	0.01	61.0 (56.8)	71.4 (69.0)	27.85 (33.34)

Note: The data in parentheses are the average mechanical properties obtained by Pan and Yu in March 1992 (1992).

Table 2.1.4 Mechanical Properties of 25AK and 50SK Sheet Steels in Longitudinal Tension at the Strain Rate of 0.0001 in./in./sec., Obtained in August 1995

Specimens	Thickness of Coupon (in.)	Average Width of Coupon (in.)	Strain Rate (in./in./sec.)	Yield Strength F_y (ksi)	Tensile Strength F_u (ksi)	Elongation in 2-inch Gage Length (%)
25AK-1-95s	0.079	0.500	0.0001	27.0	45.1	44.25
25AK-2-95s	0.079	0.499	0.0001	27.2	44.7	40.69
25AK-3-95s	0.079	0.499	0.0001	26.4	44.9	44.70
25AK-4-95s	0.079	0.499	0.0001	26.8	45.0	44.80
Average	0.079	0.499	0.0001	26.9 (24.6)	44.9 (42.8)	43.61 (N/A)
50SK-1-95s	0.078	0.498	0.0001	58.2	70.3	28.20
50SK-2-95s	0.078	0.498	0.0001	58.3	68.6	27.60
50SK-3-95s	0.078	0.499	0.0001	58.8	69.4	26.50
50SK-4-95s	0.078	0.495	0.0001	57.8	69.6	27.00
Average	0.078	0.498	0.0001	58.3 (55.0)	69.5 (67.1)	27.3 (36.09)

Note: The data in parentheses are the average mechanical properties obtained by Pan and Yu in March 1992 (1992).

Table 3.1 Comparison of Mechanical Properties of 25AK and 50SK Sheet Steels in Longitudinal Tension for Aging and Strain Rate Effect

Sheet Steel	Thickness of Coupon (in.)	Strain Rate (in./in./sec.)	Yield Strength Ratio $F_{y,97} / F_{y,92}$	Tensile Strength Ratio $F_{u,97} / F_{u,92}$	Elongation in 2-Inch Gage Length Ratio $\varepsilon_{97} / \varepsilon_{92}$
25AK	0.079	0.0001	1.06	1.05	N/A
50SK	0.078	0.0001	1.05	1.04	0.88
25AK	0.079	0.01	1.10	1.10	0.91
50SK	0.078	0.01	1.07	1.04	0.84
Sheet Steel	**Thickness of Coupon**	**Year of Test**	**Yield Strength Ratio $F_{y,0.01} / F_{y,0.0001}$**	**Tensile Strength Ratio $F_{u,0.01} / F_{u,0.0001}$**	**Elongation in 2-Inch Gage Length Ratio $\varepsilon_{0.01} / \varepsilon_{0.0001}$**
25AK	0.078	March, 1992	1.13	1.04	N/A
50SK	0.078	March, 1992	1.03	1.03	0.92
25AK	0.079	January, 1997	1.17	1.09	1.06
50SK	0.078	January, 1997	1.06	1.03	0.87
Note:					

Table 3.2 Yield Points of Steels and Computed Yield Moments

Specimen	Strain Rate	Computed Yield Moment Obtained from Tables 4.10, 4.11 and 4.12 of the 20th Progress Report			Recomputed Yield Moment by Considering the Aging Effect of Material Properties		
		F_y(ksi)(1)		$(M_y)_{comp}$ (in. -kips)	F_y(ksi)(2)		$(M_y')_{comp}$ (in. -kips)
		25AK	50SK		25AK	50SK	
3C1AZ	0.0001	24.57	54.92	26.33	25.89	56.85	27.63
3C3AZ	0.01	27.80	56.84	29.91	28.93	58.47	30.96
3C1AS	0.0001	24.57	54.92	32.05	25.89	56.85	32.85
3C1AK	0.0001	24.57	54.92	38.21	25.89	56.85	39.42
3C3AK	0.01	27.80	56.84	40.87	28.93	58.47	41.90
3C3BK	0.01	27.80	56.84	40.93	28.93	58.47	41.97

(1) The yield points of steels are based on the coupon tests conducted by C. L. Pan in March 1992.

(2) The yield points of steels are interpolated from Figures 3.3 and 3.5 for February 1994.

Table 3.3 Comparison of Computed Yield Moments for Aging Effect

Specimen	$(M_y)_{test}$ (1)	$(M_y)_{comp}$ (2)	$(M'_y)_{comp}$ (3)	(1)/(2) (4)	(1)/(3) (5)	(4)-(5) (6)
3C1AZ	23.80	26.33	27.63	0.904	0.861	0.043
3C3AZ	26.84	29.91	30.96	0.897	0.867	0.030
3C1AS	29.11	32.05	32.85	0.908	0.886	0.022
3C1AK	33.90	38.21	39.42	0.887	0.860	0.027
3C3AK	36.53	40.87	41.90	0.894	0.872	0.022
3C3BK	36.56	40.93	41.97	0.893	0.871	0.022

Note: Column (2) represents the values listed in the 20th Progress Report.
Column (3) represents the recomputed values by using the same procedure discussed in the 20th Progress Report and considering the aging effect.

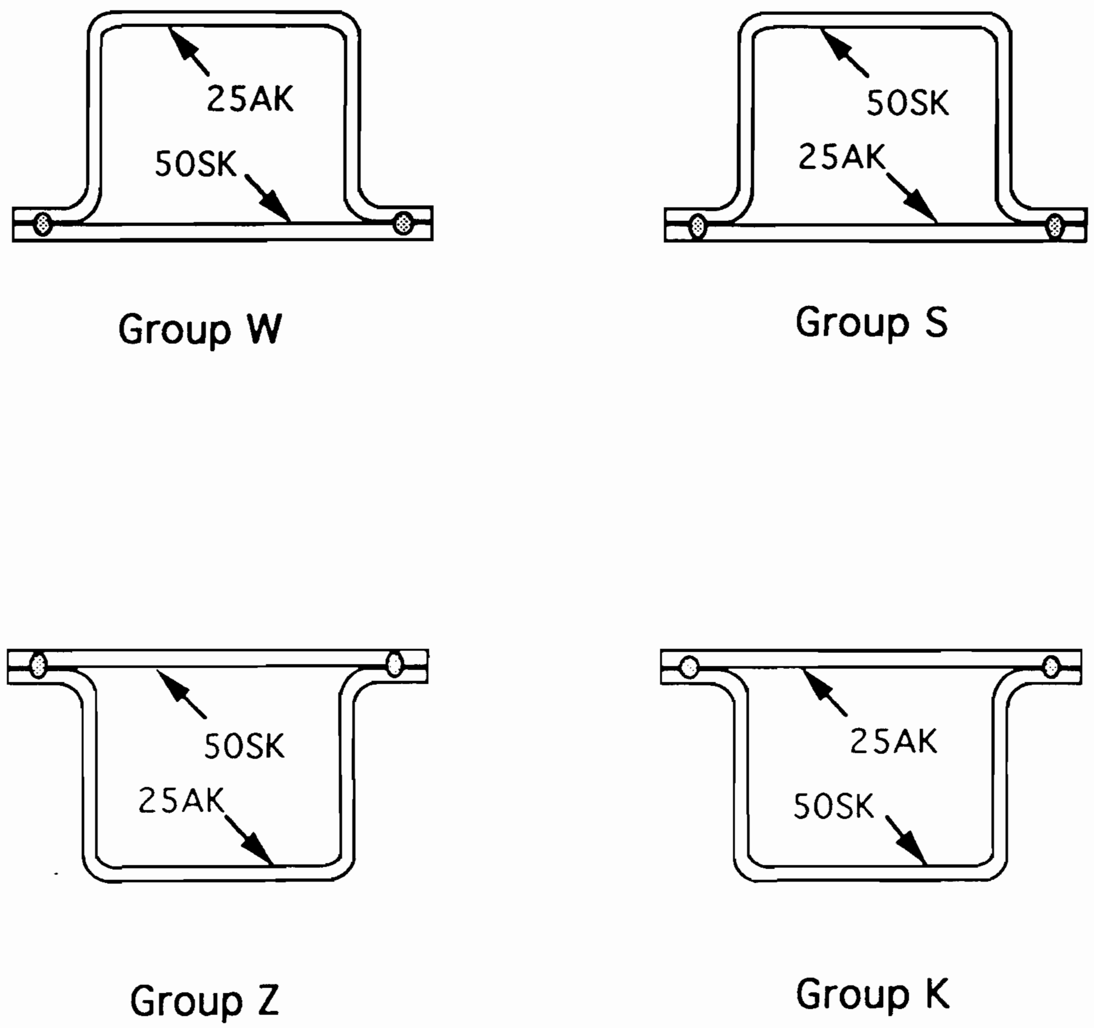

Figure 2.1.1 Cross Section of the Hybrid Beams Tested by Pan and Yu (1995)

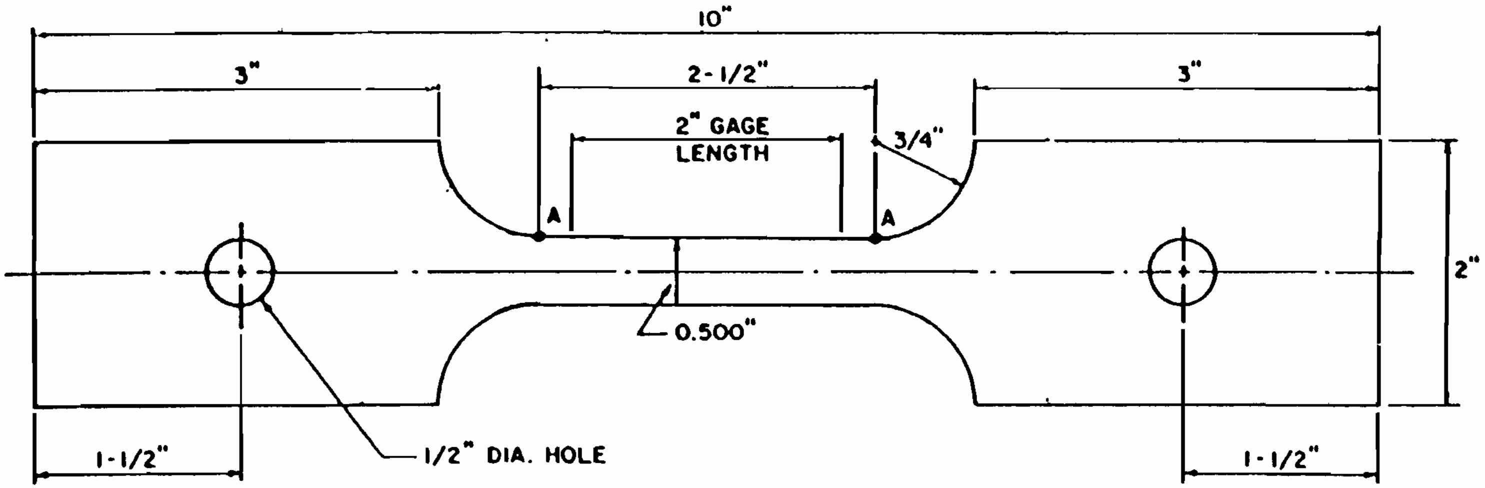

Figure 2.1.2 Nominal Dimensions of Tension Coupons Used for 25AK and 50SK Sheet Steels

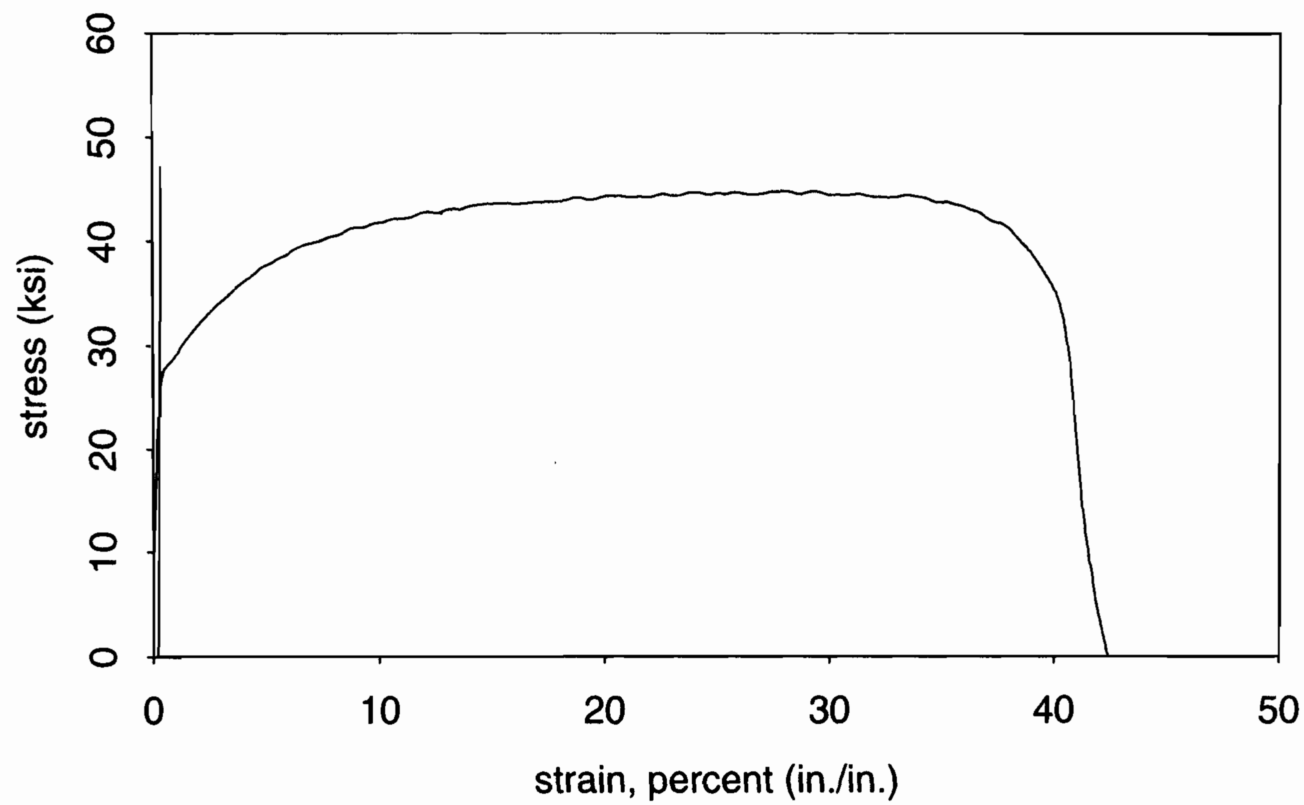

Figure 2.3.1 Stress-strain relationship of coupon 25AK-3-97s (Strain Rate: 0.0001 in./in./sec.)

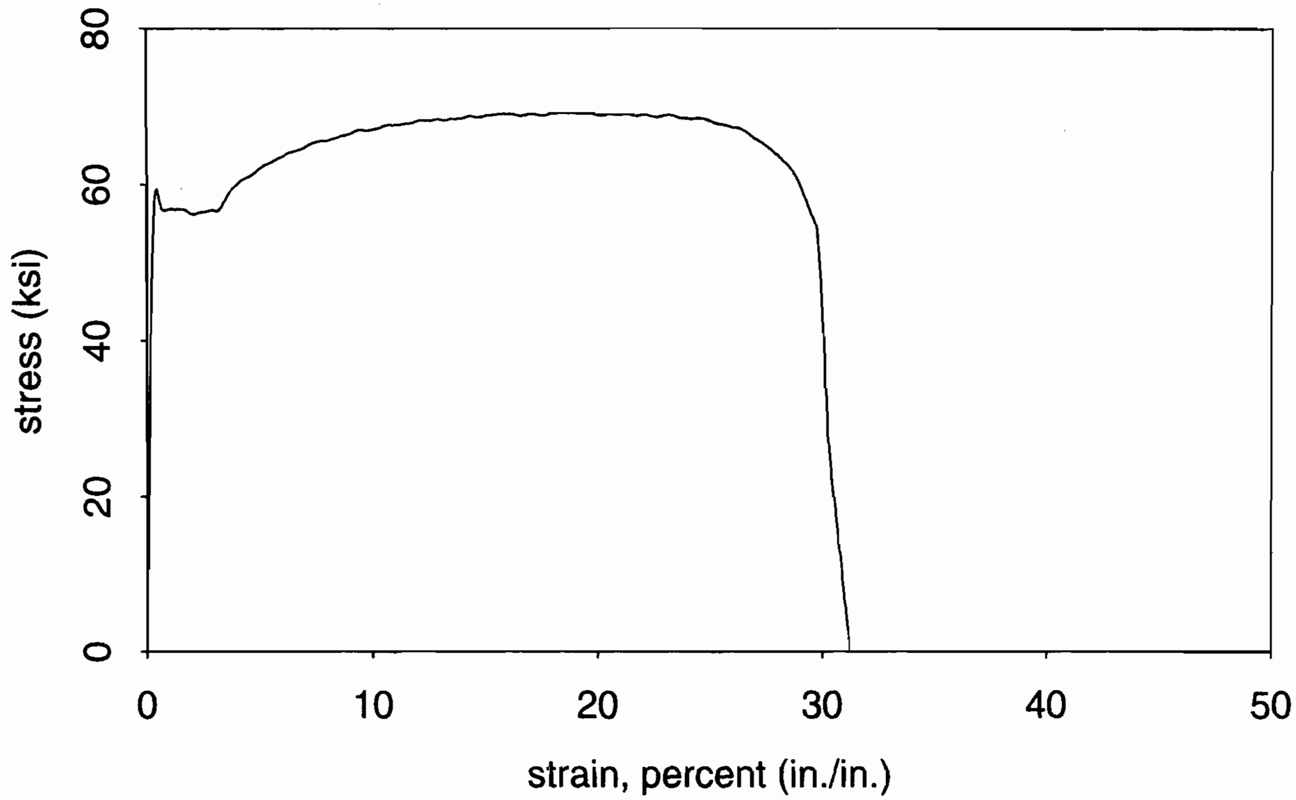

Figure 2.3.2 Stress-strain relationship of coupon 50SK-1-97s (Strain Rate: 0.0001 in./in./sec.)

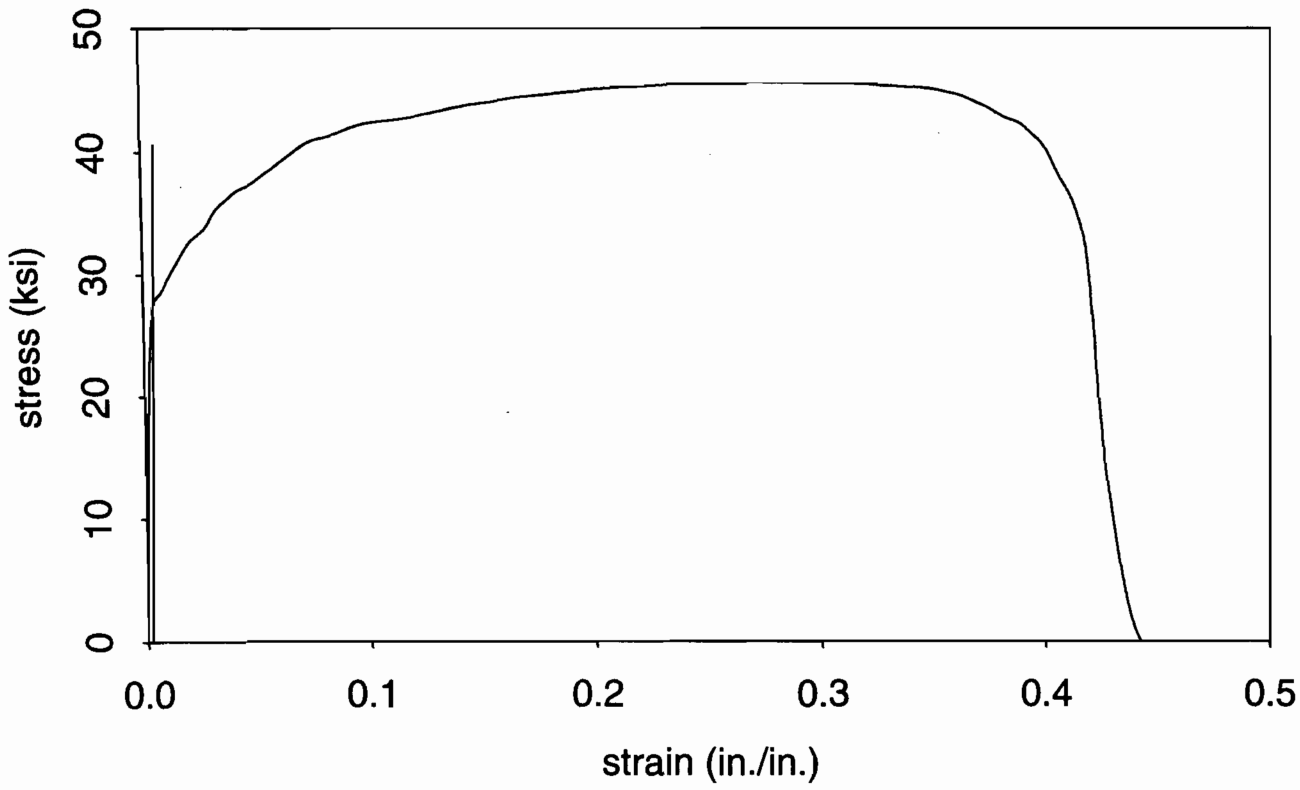

Figure 2.3.3 Stress-strain relationship of coupon 25AK-1-95s (Strain Rate: 0.0001 in./in./sec.)

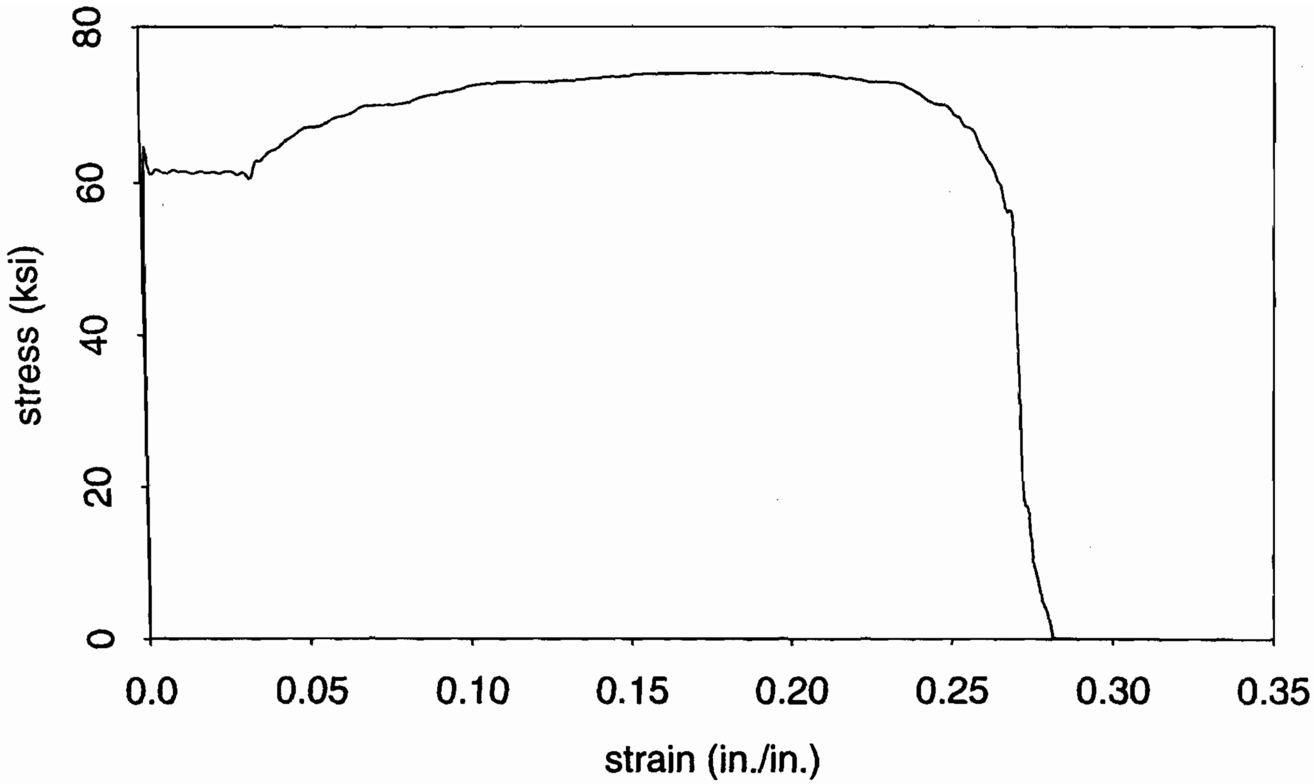

Figure 2.3.4 Stress-strain relationship of coupon 50SK-1-95s (Strain Rate: 0.0001 in./in./sec.)

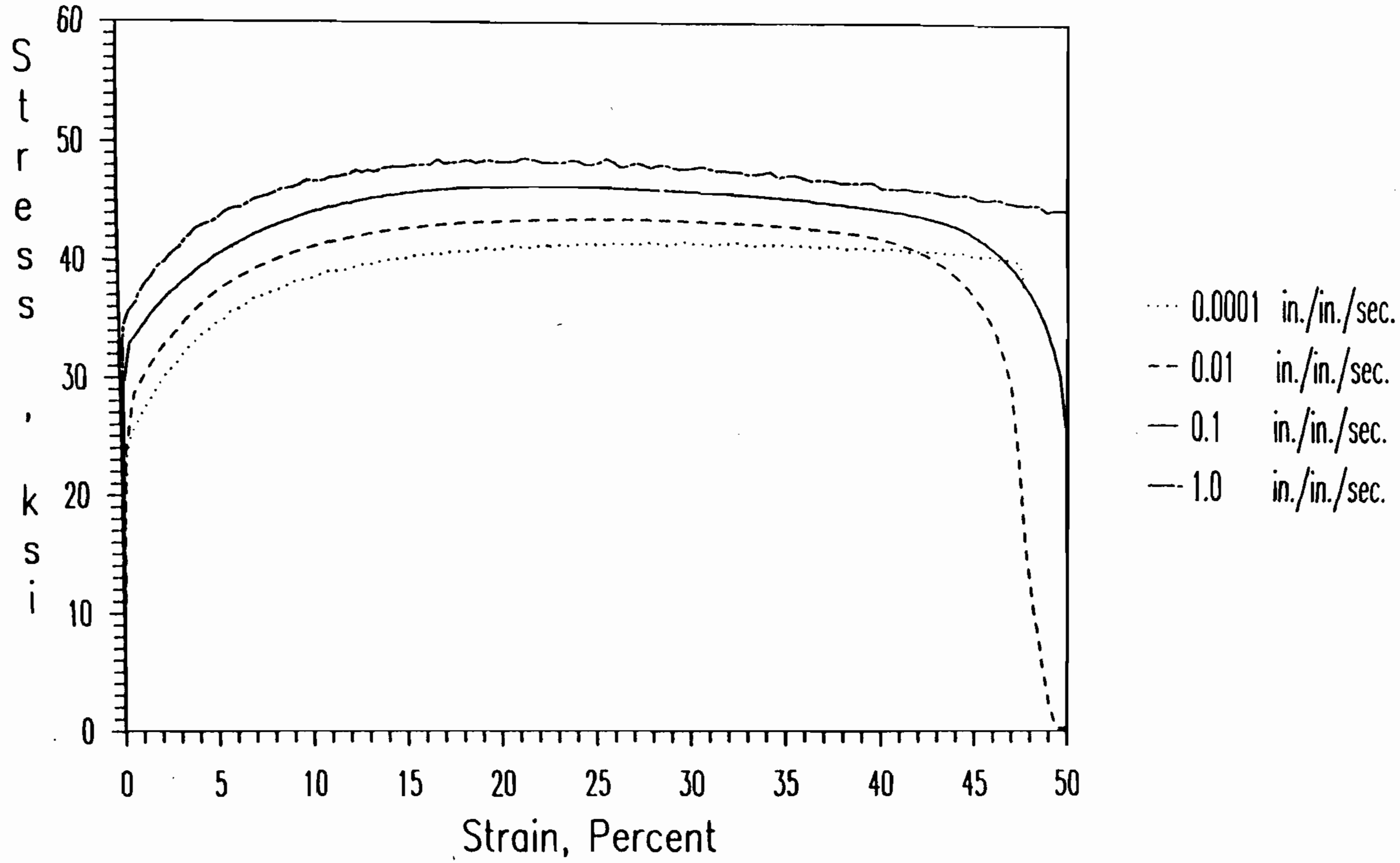

Figure 2.3.5 Stress-strain relationship for 25LT steel under different strain rates (Pan and Yu 1992)

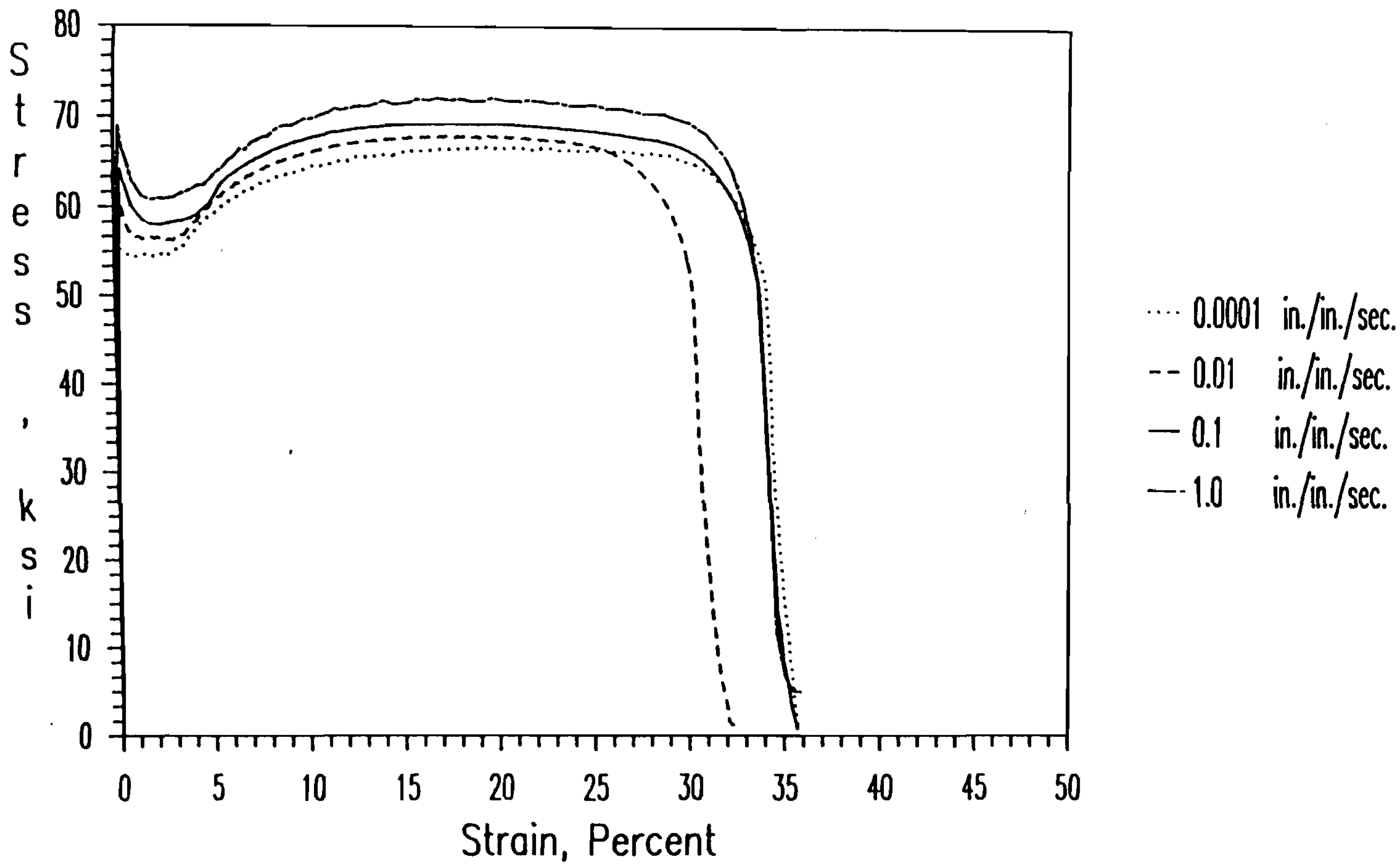

Figure 2.3.6 Stress-strain relationship for 50LT steel under different strain rates (Pan and Yu 1992)

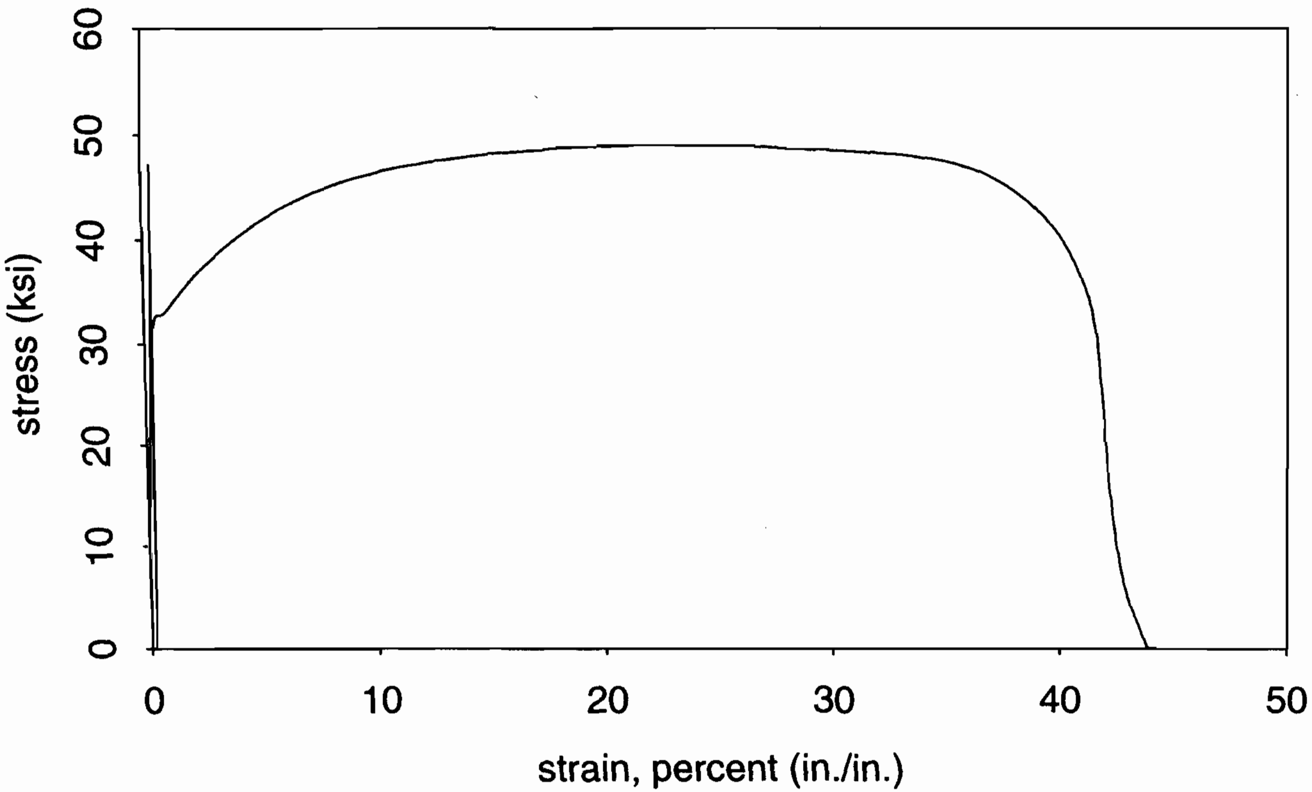

Figure 2.3.7 Stress-strain relationship of coupon 25AK-3-97f (Strain Rate: 0.01 in./in./sec.)

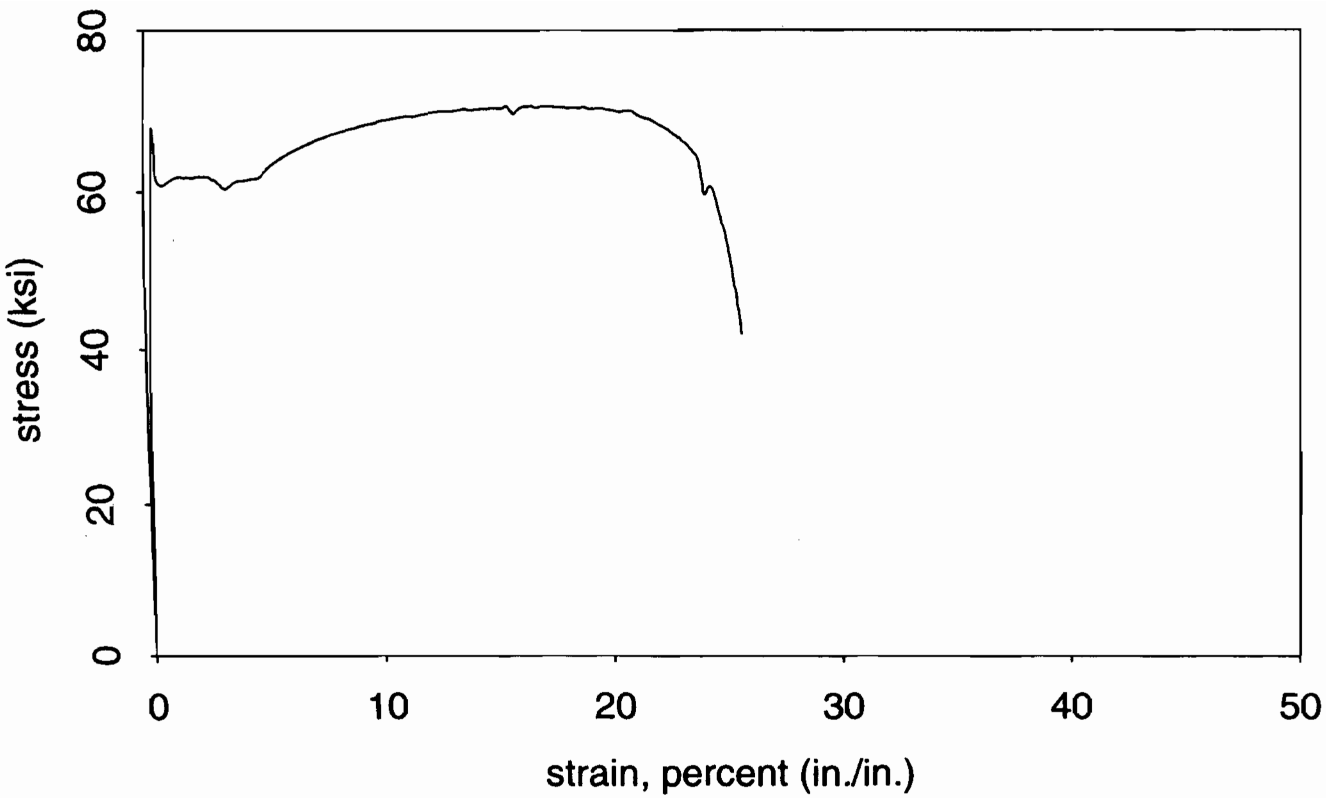

Figure 2.3.8 Stress-strain relationship of coupon 50SK-1-97f (Strain Rate: 0.01 in./in./sec.)

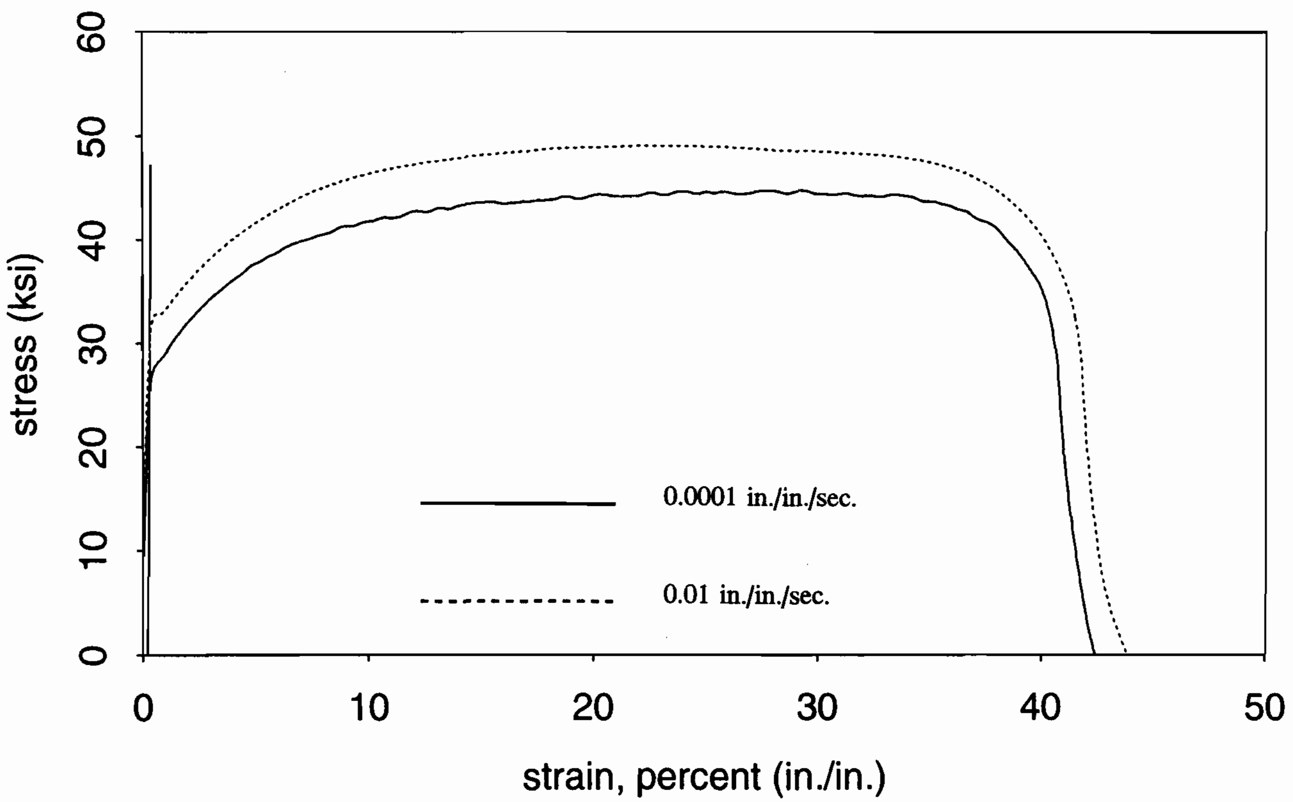

Figure 3.1 Comparison of stress-strain relationships between coupon 25AK-3-97s and coupon 25AK-3-97f

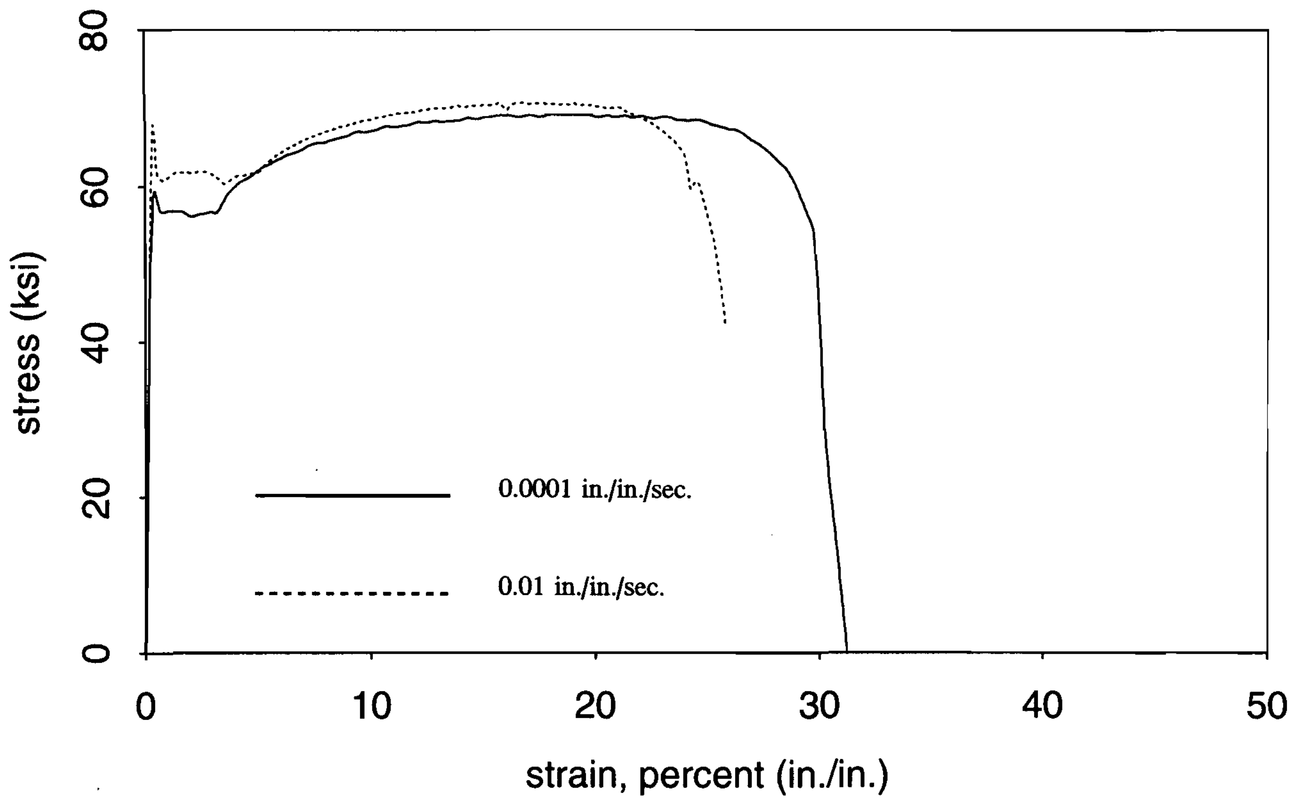

Figure 3.2 Comparison of stress-strain relationships between coupon 50SK-1-97s and coupon 50SK-1-97f

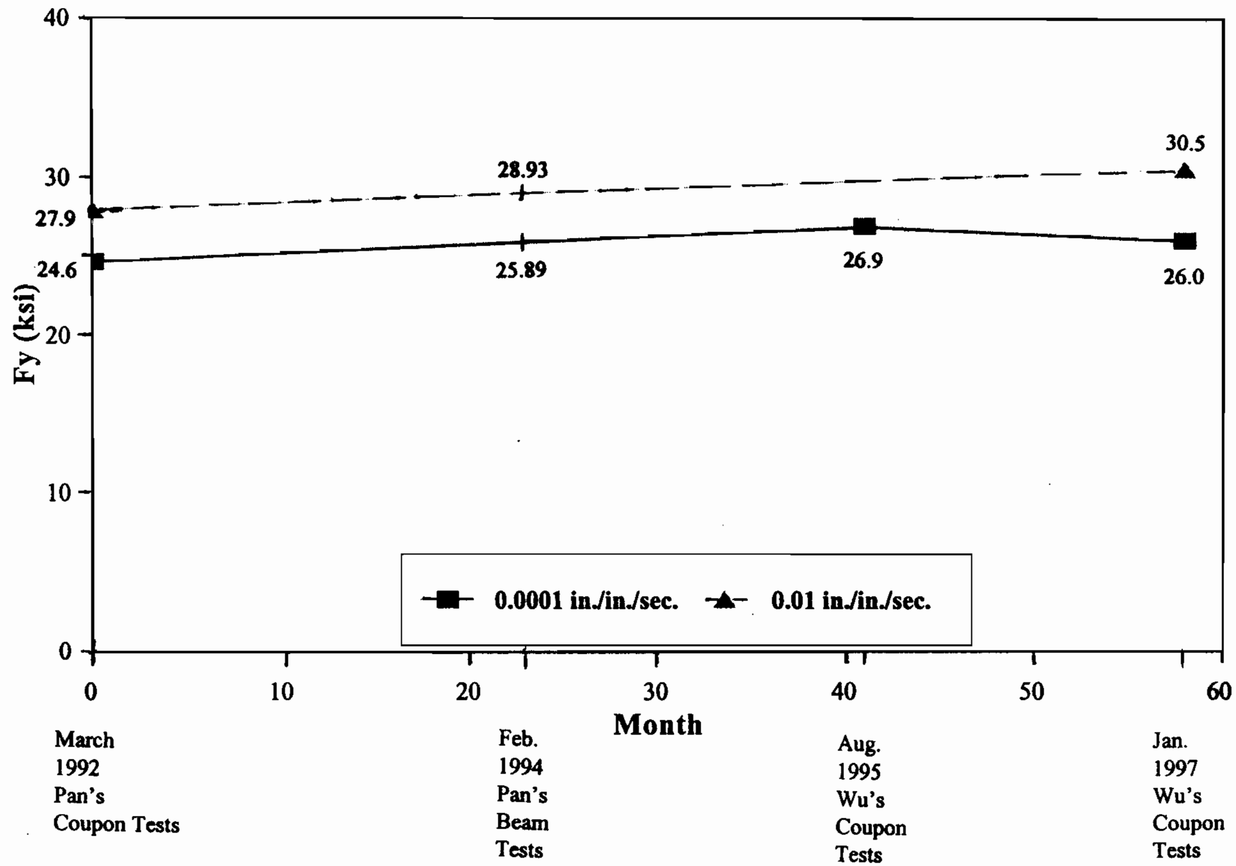

Figure 3.3 Average yield strength vs. Time for 25AK steel

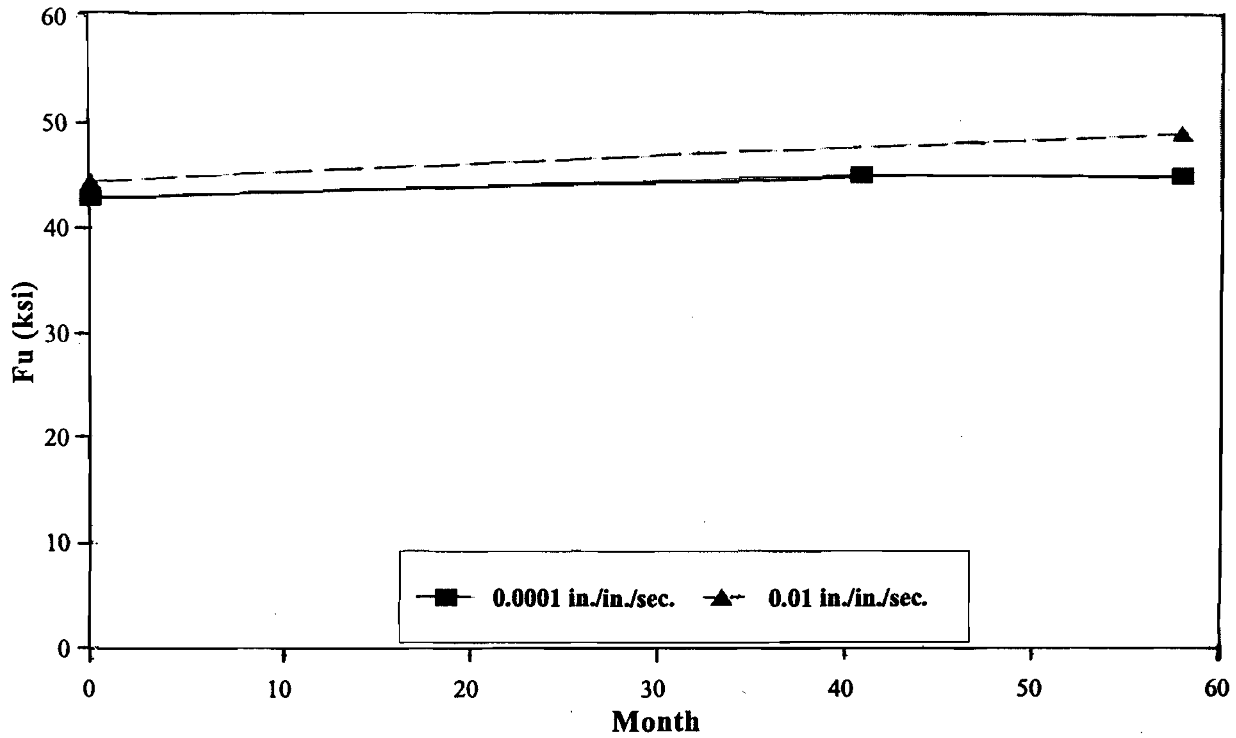

Figure 3.4 Average tensile strength vs. Time for 25AK steel

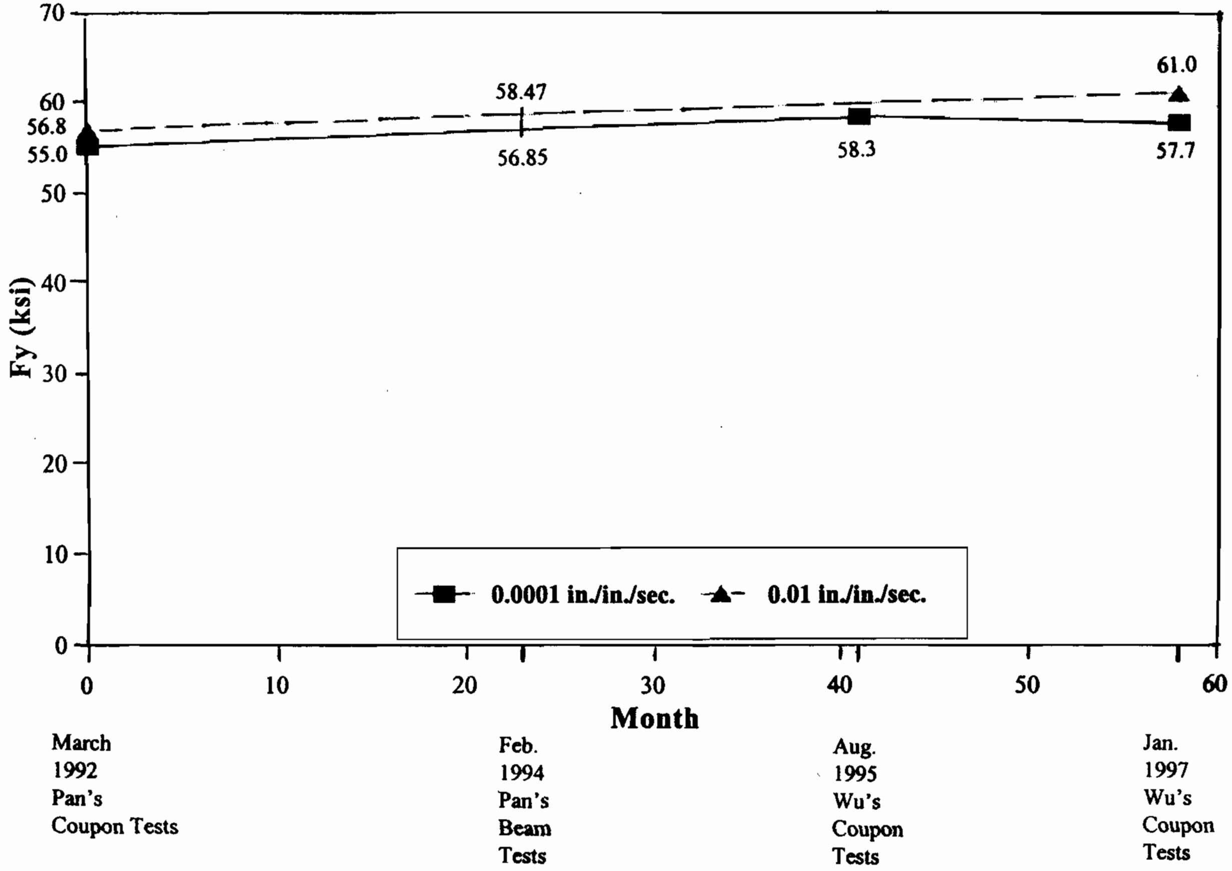

Figure 3.5 Average yield strength vs. Time for 50SK steel

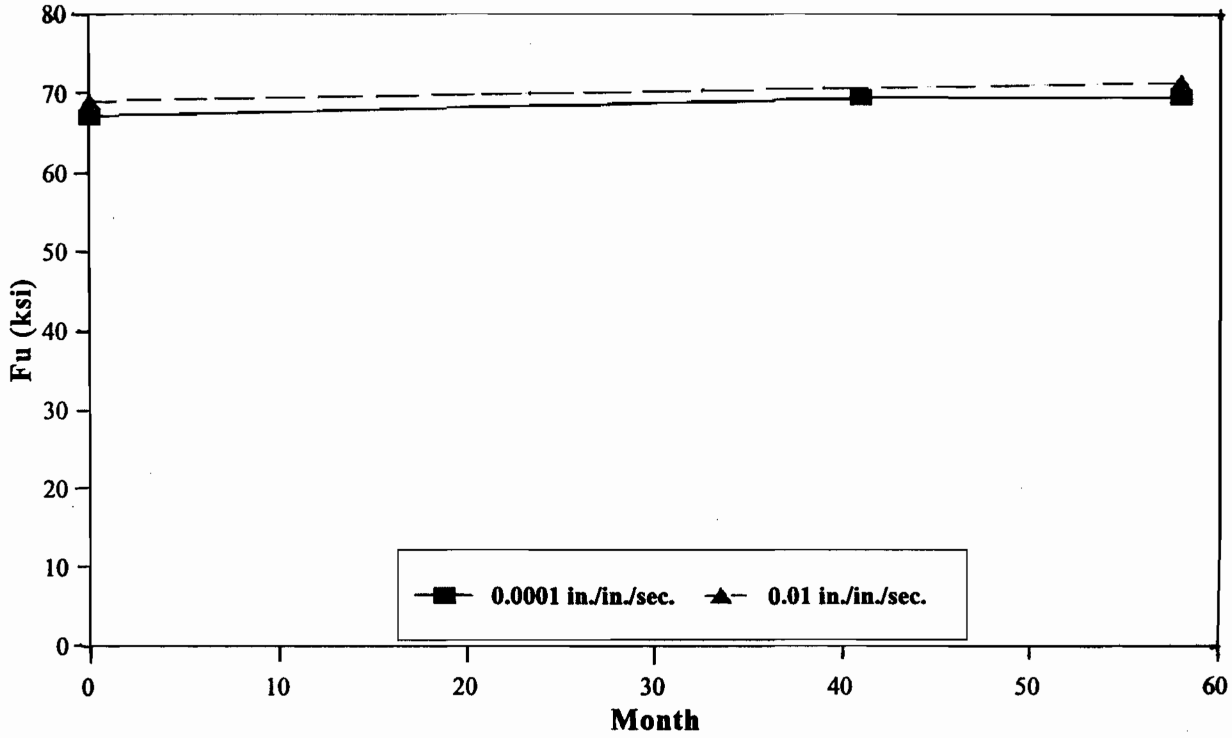

Figure 3.6 Average tensile strength vs. Time for 50SK steel