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Relative Temperature Indices of Industrial Thermosetting Laminates

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Foreword

The Industrial Laminate Section of the National Electrical Manufacturers Association represents the major manufacturers of industrial laminated plastics. It is an industry group which conducts activities of interest not only to customers and manufacturers, but also to the general public which ultimately benefits in safety, economy, and convenience, through such programs as standardization, safety and engineering, statistics and marketing, and other projects of mutual interest.

Industrial laminates consist of fibrous materials such as cellulose paper, cotton, glass, or asbestos fabric; or a mat of random-laid glass or other fibers impregnated or coated with a thermosetting resin binder and laminated under pressure and high temperature into hard, solid products. These products have useful properties of high mechanical strength, good electrical insulating properties and serviceability at elevated temperatures when used within the range of temperatures indicated in Table 4-1 of this publication.

The Industrial Laminate Section has supported applied research and development at the Johns Hopkins University, the University of Delaware, and at the University of Cincinnati for the following reasons:

a. The need for an unbiased source of professional quality work on test method development
b. The testing of industry offerings of industrial laminates for the purpose of guiding NEMA standards for these products
c. Special studies of technology related to industrial laminates

Much of the work at these university laboratories has been directed at obtaining data for industrial laminates under the special environmental and test conditions of the Underwriters Laboratories Inc. Representatives of UL have cooperated with these NEMA-sponsored laboratories through interlaboratory correlations of test methods, and, as in the case of the publication at hand, have developed relative temperature indices of the laminates.

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Section 1
REFERENCED STANDARDS

In this publication, reference is made to the standards listed below. Copies are available from the indicated sources.

International Electrotechnical Commission
1, rue de Varembe
Geneva, Switzerland

American National Standards Institute, Inc.
11 West 42nd Street
New York, NY 10036

Pub. No. 216-1 — *Guide for the Determination of Thermal Endurance Properties of Electrical Insulating Materials*

Also available in other countries from their National Committees for IEC.

The Institute of Electrical and Electronic Engineers, Inc.
445 Hoes Lane
Piscataway, NJ 08854-1331

Pub. No. 1-1986 — *General Principles Upon which Temperature Limits Are Based in the Rating of Electric Equipment*

Pub. No. 98-1984 — *Guide for the Preparation of Test Procedures for the Thermal Evaluation and Establishment of Temperature Indexes of Solid Electrical Insulating Materials*

Pub. No. 99-1980 — *Guide for the Preparation of Test Procedures for the Thermal Evaluation of Insulation Systems for Electric Equipment*

Pub. No. 101-1987 — *Guide for the Statistical Analysis of Thermal Life Test Data*

American Society for Testing and Materials
1916 Race Street
Philadelphia, PA 19103-1187

Pub. No. D2034 — *Standard Method for Thermal Evaluation of Rigid Electrical Insulating Materials*

Underwriters Laboratories, Inc.
333 Pfingsten Road
Northbrook, IL 60062

Standard 746B-1992 — *Polymeric Materials—Long Term Property Evaluation*

Standard 746C — *Polymeric Materials—Use in Electrical Equipment Evaluations*

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Section 2
INTRODUCTION

This report on the thermal aging of industrial thermosetting laminates is based on a test program carried out at the NEMA Industrial Laminate Research and Development Facility at the University of Delaware, in cooperation with Underwriters Laboratories, Inc. (UL) to determine the relative thermal indices (general) temperature ratings of industrial laminate sheets, rods, and tubes (rolled and molded).

A basic objective of this program was to develop engineering information which would assist the user in the selection of the proper grade of thermosetting industrial laminate best suited for use in electrical insulation systems and products that may operate at higher than room temperatures. Heretofore, the design engineer has not had such industry information available based on actual tests.

All characteristic measurements were made under standard laboratory conditions and are not necessarily indicative of characteristics of the material at an elevated temperature.

An additional objective of the program was to provide basic engineering data from which UL could more readily grant:

a. Recognition of individual industrial laminate grades
b. Listing of end-use products incorporating industrial laminate as a component material

To design engineers and users of industrial laminates who submit end products for UL listing, this means that additional testing costs may be reduced or eliminated and that the time needed for listing will be greatly shortened.

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Section 3
HISTORY

Earlier thermal classification of electrical insulating materials were based on chemical compositions; but with the advances in polymer chemistry, insulating materials were being produced that were so complex that simple chemical description became almost meaningless.

Beginning with the June 1957 edition of AIEE (now IEEE) Publication No. 1, the method of establishing temperature classification was changed to one based on operating life as determined by test or actual experience.

This concept of thermal classification of insulating materials by test is described in the current editions of IEEE Publications No. 1 and 98 and ASTM D-2304.

A joint project between Underwriters Laboratories, Inc., the University of Delaware, and NEMA was established to obtain long time thermal degradation data of industrial laminates in order to provide a guide to their selection in insulation systems and products.

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Section 4
RELATIVE TEMPERATURE INDICES

4.1 DEFINITION

Relative Temperature Index is defined as an index that allows relative comparisons of the temperature capability, of insulating materials or insulation systems based on specified, controlled test conditions. The temperature index is used to provide a temperature "designation" for insulating materials, and is related to the temperature at which the material will provide a specified life as determined by test or service experience. (IEC Publication No. 216-1.) This indexing method effectively separates the temperature capabilities of individual insulating materials from the temperature classification of insulation systems. (IEEE Publication No. 1.)

From the data obtained in these test programs, the Relative Temperature Indices were developed as shown in Table 4-1. which lists a maximum continuous use temperature for each material. (Data for Grades CEM-1 and CEM-3 were obtained by a different program, as explained in 3.2)

These indices were established, as discussed in detail later, by comparing the degradation of properties of industrial laminates under controlled test procedures with the degradation of NEMA Grade XXXPC. This grade was chosen because of its long history as a grade capable of continuous use at 125°C.

Table 3-1 can be interpreted in the following manner: 1/6 inch (1.588 mm) Grade A. for example, will retain its mechanical and electrical properties after exposure to thermal degradation at 155°C, as well as XXXPC does at 125°C. In this way the Relative Temperature Indices or upper operating temperature confidence levels have been established for the NEMA grades listed in Table 3-1.

The purpose of assigning a definite relative temperature index to each material is to facilitate comparisons between materials and to provide a single designation of temperature capability for standardization purposes. The severity, of the tests and their duration are arbitrarily chosen for convenience, accuracy, and economy in testing. Therefore, the life expectancy under test conditions may be shorter than, and may have no uniform relation to, the life expectancy of the material in actual service. Materials of a given relative temperature index may be used as components of complete insulation systems that are assigned widely different limiting temperatures, depending on the results of thermal evaluation tests of the insulation system (IEEE Publication No. I).

Thermal endurance curves for all grades tested are given in the Appendix.

The Relative Temperature Index is a guide and does not imply a thermal classification or a limitation on use in equipment. It is used most suitably for comparing materials which have been evaluated under controlled conditions. Temperature classification for the purpose of rating electrical machines should be defined in terms of the thermal endurance of the insulation system (IEEE Publication No. 1).

4.2 RELATIVE TEMPERATURE INDICES OF COMPOSITE GRADES CEM-1 AND CEM-3

Unlike the data for all other grades, which were obtained from UL/NEMA joint investigation, the Relative Temperature Indices of the composite grades CEM-1 and CEM-3 were obtained from data provided by Underwriters Laboratories, Inc. UL pooled all the data in their files for at least three brands each of recognized composite grades, and treated the pooled data as though it were thermal aging data for a single brand of each grade.

For each of the brands in the UL analysis, the endpoint times at the various aging temperatures were used to determine the Arrhenius curve by, the usual regression analysis procedure. The actual thermal aging of the brands involved were not necessarily all done in the same testing laboratory and the choice of aging temperatures for the different brands led to more temperature points for the Arrhenius curves than usual, as seen in Table 5-2.

The Relative Temperature Indices of the two grades for the two thicknesses and two properties were determined by UL in the usual comparison with a reference or control material.

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Table 4-1

RELATIVE TEMPERATURE INDICES OF INDUSTRIAL THERMOSETTING LAMINATES (SHEETS, RODS AND TUBES)

NEMA Grade	Base Material	Resin	Nominal Thickness (in.)*	Electrical Test Index (Electric Strength)**	Mechanical Test Index (Flexural Strength)**
X	Paper	Phenolic	over 0.030	130	130
XP	Paper	Phenolic	over 0.030	130	130
XPC	Paper	Phenolic	over 0.030	130	130
XX	Paper	Phenolic	over 0.031 to 0.062	130	130
			over 0.062	140	140
XXP	Paper	Phenolic	0.031 to 0.062	130	130
			over 0.062	140	140
XXX	Paper	Phenolic	0.031 to 0.062	130	130
			over 0.062	140	140
XXXP	Paper	Phenolic	over 0.030	125	125
XXXPC	Paper	Phenolic	over 0.030	125	125
C	Cotton Fabric	Phenolic	0.031 to 0.062	85	85
			over 0.062	115	125
CE	Cotton Fabric	Phenolic	0.031 to 0.062	85	85
			over 0.062	115	125
L	Cotton Fabric	Phenolic	0.031 to 0.062	85	85
			over 0.062	115	125
LE	Cotton Fabric	Phenolic	0.031 to 0.062	85	85
			over 0.062	115	125
A	Asbestos Paper	Phenolic	0.031 to 0.062	140	140
			over 0.062	155	155
AA	Asbestos Fabric	Phenolic	0.031 to 0.062	140	140
			over 0.062	155	155
G-3	Continuous-Filament Glass Cloth	Phenolic	over 0.030	140	170
G-5	Continuous-Filament Glass Cloth	Melamine	over 0.030	†	140
G-7	Continuous-Filament Glass Cloth	Silicone	over 0.030	170	220
G-9	Continuous-Filament Glass Cloth	Melamine	over 0.030	†	140
G-10	Continuous-Filament Glass Cloth	Epoxy	over 0.030	130	140
G-11	Continuous-Filament Glass Cloth	Epoxy	0.031 to 0.062	140	160
			over 0.062	170	180

(continued)

NOTE: Any manufacturer of any grade of industrial laminate may obtain relative temperature indices (electrical and mechanical) by an individual thermal aging program according to procedures laid down in UL standard 746B. These indexes may then be higher than those listed in Table 3-1.

* 0.031 inch (0.8 mm); 0.062 inch (1.6 mm)

** Based on a reference standard for XXXPC.

† Not recommended for electrical application at elevated temperatures.

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Table 4-1 *(continued)*

NEMA Grade	Base Material	Resin	Nominal Thickness (in.)*	Electrical Test Index (Electric Strength)**	Mechanical Test Index (Flexural Strength)**
FR-2	Paper	Phenolic	0.031 to 0.062 over 0.062	75 105	75 105
FR-3	Paper	Epoxy	0.031 to 0.062 over 0.062	90 110	90 110
FR-4	Continuous-Filament Glass Cloth	Epoxy	over 0.030	130	140
FR-5	Continuous-Filament Glass Cloth	Epoxy	0.031 to 0.062 over 0.062	140 170	160 180
GPO-1	Random-laid Glass Fiber Mat	Polyester	over 0.062	105††	105††
GPO-2	Random-laid Glass Fiber Mat	Polyester	over 0.062	130▲	160▲
GPO-3	Random-laid Glass Fiber Mat	Polyester	over 0.062	120▲	140▲
CEM-1	Cellulose Paper Core, Continuous-Filament Glass Cloth Faces	Epoxy	over 0.030	130	140
CEM-3	Non-woven Glass Core, Continuous-Filament Glass Cloth Faces	Epoxy	over 0.030	130	140

* 0.031 inch (0.8 mm); 0.062 inch (1.6 mm)

** Based on a reference standard for XXXPC.

† Not recommended for electrical application at elevated temperatures.

†† Maximum continuous use temperature assigned by Underwriters' Laboratories, Inc., in UL Standard 746C.

▲ The maximum continuous use temperature recognized by UL for the generic types GPO-2 and GPO-3 is 105. Most brands of GPO-2 and GPO-3 have the indices of 130 and 120 shown here, established by actual thermal aging.

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Section 5
THEORY

The test program was based on the assumption that heat is the chief cause of insulation deterioration. Other factors being equal, thermal degradation is accelerated as the temperature is increased. A fairly precise method of determining performance at elevated temperature is provided by the concept that the logarithm of thermal endurance is a function of the reciprocal of the absolute temperature. The logarithms of accumulated times to end points obtained in thermal evaluation tests at three or more temperatures are plotted against the reciprocal of the absolute temperatures. This plot is called an Arrhenius curve.

The Arrhenius equation describes the temperature dependence of the "velocity coefficient" of chemical reactions and can be used to approximate the relationship between insulation life and temperature. This equation indicates that the logarithm of insulation life should be a linear function of the reciprocal of absolute temperature. Regression analysis is the technique used to determine the best estimate of the slope and intercept of the straight line that relates the logarithm of insulation life to the reciprocal of absolute temperature.

The Arrhenius equation used for calculating life at a chosen temperature and written for use with natural logarithms to the base "e" is as follows:

$$k = Ae^{-(E/RT)}$$

Where:

k = specific reaction rate
A and -E/R = constants
T is expressed in Kelvin (°C + 273)

Thermal endurance (Arrehnius) curves can be used to compare the relative thermal life of insulating materials. The test results for an accepted material of long service experience is used as a reference; in the case of this investigation, Grade XXXPC industrial laminate has been established by experience as being capable of continuous use at 125°C, and its endurance curve provides a basis for comparison with the thermal capabilities of other grades of industrial laminates. The thermal endurance curves are used to establish a relative temperature rating or index which provides a simple nominal number for comparing the thermal capability of other industrial thermosetting laminates.

Arrhenius curves for all grades tested are given in the Appendix.

NOTES

1. The "Confidence Limits of the Mean" shown on the Arrhenius curves in the appendix, express the fact that repeated tests would prove that 99.7% of the mean of all test values in the specified grade would fall within the 95% limit selected based on a normal distribution.

2. The 95% confidence limits of the mean for several grades and temperatures show a U-shaped curve. In these cases, extrapolation of data beyond the four points on the regression line would be invalid due to the large variance in the aging characteristics of the material tested. In any case, extrapolation of the linear regression line beyond the test points shown must be carefully correlated with the degree of variation of the 95% confidence limits of the mean.

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Section 6
TEST PROCEDURES

6.1 SPECIMENS AND GRADES TESTED

Because of similarities in types of resins and fillers used in the makeup of grades, it was not considered necessary to conduct tests on all the NEMA grades of laminates for which standards have been established, as the typical grades selected were representative of other grades.

Table 6-1 is a summary of the grades tested and the other grades which they represent.

Tests were made on specimens 0.031 inch (0.8 mm) and 0.062 (1.6 mm) in thickness. No tests were made on thicker materials because of the time involved and the difficulty in making tests. Thicker materials are expected to perform at least as well as 0.062 inch (1.6 mm) material; and, therefore, the temperature capability of 0.062 inch (1.6 mm) material is conservative for thicker material.

Five test specimens of each grade tested were selected at random from the following companies, all of whom supplied at least one tested grade:

a. The Budd Company Polychem Division
b. Formica Corporation (A wholly owned subsidiary of American Cyanamid)
c. General Electric Company
d. The Glastic Company
e. Oak Materials Group, Inc.
f. The Item Fibre Company
g. NVF Company
h. UOP Norplex Division
i. Panelyte Industrial Division Thiokol Chemical Corp.
j. The Richardson Company Insurok Division
k. Spaulding Fibre Co., Inc.
l. Synthane-Taylor Corp. (An Alco Standard Company)
m. Westinghouse Electric Corporation

Table 6-1
MATERIALS TESTED

Grades Tested	Other Grades Represented
XP	X, XPC
XX	XXP, XXX
XXXPC	XXXP
FR-2	—
FR-3	—
CE	C, L, LE
FR-4	G-10
A	AA
G-9	G-5
G-7	—
G-3	—
G-11	FR-5
GPO-2	—
GPO-3	—
CEM-1	CEM-3 (Electric Strength)
CEM-3	—

6.2 TEST TEMPERATURE

All specimens were tested under standard laboratory conditions after aging. Experience has shown that the long-term degradation rate, as determined by change in either mechanical strength or electric strength, is independent of the temperature at which the property is measured. Since it is more convenient to measure these properties at room temperature than at elevated temperature, only room temperature measurements are specified. It should be cautioned, however, that a material that is judged to have acceptable thermal degradation characteristics for a given use temperature may not be suitable in a given application at that temperature because of insufficient initial properties strength at this use temperature (as per ASTM D 2304.)

Curves of property values measured at aging temperature and at room temperature after aging and that are plotted against hours of exposure parallel each other after long-time aging; it is necessary only to select an end-point far enough out on the curve. An end-point thus suitably chosen gives a point on the Arrhenius curve.

(See curves in Appendix.)

6.3 AGING TEMPERATURES

Industrial laminates were aged at the temperatures shown in Table 6-2.

6.4 TESTS AND TEST METHODS

Flexural strength was selected as representing mechanical characteristics. Electric strength was selected as representing electrical characteristics.

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The test methods and number of specimens for each Specimens test were as follows.

Test Performed	Test Method	Number of Specimens Eact Test	
		Condition A*	Aged
Flexural Strength	ASTM D-790	10	5
Electric Strength	ASTM D-149 [6 × 6 inch (152.4 × 152.4 mm) specimen tested in air; perpendicular to laminations; short-time test; voltage increase 500 v/sec]	10	5

* Condition A means "as received, no special conditioning."

Specimens were placed in forced-air-circulating ovens maintained at the constant aging temperature. Periodically the number of specimens required for the test were removed from the oven, conditioned at 23°C and 50% relative humidity for a minimum of 48 hours and then subjected to the required test. The procedure followed the program recommended in IEEE Publications No. 1, 98, 99 and 101.

Table 6-2
THERMAL AGING TEMPERATURES

	Aging Temperature—Degrees C															
Grade	90	120	130	140	150	160	165	170	180	190	200	210	220	230	270	280
XP	—	—	X	—	X	X	—	—	X	—	—	—	—	—	—	—
XX	—	—	X	—	X	X	—	—	X	—	—	—	—	—	—	—
XXXPC	—	—	X	—	X	X	—	—	X	—	—	—	—	—	—	—
CE	—	—	X	—	X	X	—	X	—	—	—	—	—	—	—	—
A	—	—	—	—	F	—	—	X	—	X	X	—	E	—	—	—
G-3	—	—	—	—	—	E	—	—	F	X	—	X	—	X	—	—
G-7	—	—	—	—	—	—	—	—	—	E	—	X	—	X	X	F
G-9	E	E	—	—	F	X	—	X	—	X	—	—	—	—	—	—
G-11	—	—	—	—	—	—	—	—	—	X	X	X	X	—	—	—
FR-2	—	—	X	—	X	X	—	—	X	—	—	—	—	—	—	—
FR-3	—	—	X	—	X	X	—	—	X	—	—	—	—	—	—	—
FR-4	—	E	—	—	X	F	—	X	—	F	E	—	—	—	—	—
CEM-1	—	—	—	—	X	F	X	X	—	X	X	X	E	—	—	—
CEM-3	—	—	—	F	F	F	—	F	F	F	—	—	—	—	—	—
GPO-2	—	—	E	—	E	E	—	E	—	F	F	F	F	—	—	—
GPO-3	—	E	E	E	E	E	—	F	—	F	F	F	—	—	—	—

X—Indicates both Flexural and Electric Strength Tests

E—Indicates Electric Strength Test Only

F—Indicates Flexural Strength Test Only

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Section 7
DETERMINATION OF RELATIVE TEMPERATURE INDEX

To illustrate how relative temperature index is determined, the results of aging and method of evaluating 0.031 inch (0.8 mm) thick NEMA Grade A are shown in Figures 7-1 and 7-2.

Figure 1 shows the degradation of the flexural and electric strengths of Grade A at each of the four aging temperatures. The time at which 50 percent degradation of flexural strength occurred was considered the end--point for that temperature. Figure 7-1A shows the degradation of flexural strength of Grade GPO-2.

Selection of this end-point is based on the assumption that performance requirements for mechanical and electric strength in most product standards have a safety factor of at least 2:1. This safety factor can be lost due to thermal degradation without resulting in premature mechanical or electrical failure. The end-point at each aging temperature was then used to construct the time-temperature plot (regression line). This resulted in the plot of a straight line shown in Figure 7-2 and identified as "0.031" Grade A.

The other slanted line in Figure 7-2 represents the time-temperature plot (regression line) for the control material, 0.031 inch (0.8 mm) thick NEMA Grade XX-XPC, obtained by subjecting XXXPC to the same aging program as Grade A. Grade XXXPC has a recognized index by Underwriters Laboratories of 125°C based on acceptable, continuous, known service experience in general-use applications at this temperature.

To obtain the relative temperature index for Grade A material, enter the time-temperature graph at 125°C (point 1). Proceed vertically to the regression line for XXXPC (point 2). Proceed horizontally to the regression line for Grade A (point 3). The temperature value of 140°C (point 4) thus obtained is the relative temperature index for 0.031 inch (0.8 mm) thick Grade A based on flexural strength.

Grade A material can be reasonably expected to be useful at 140°C in the same way that XXXPC is useful at 125°C.

Regression analysis, based on the method of least squares, was used to provide the curves used in obtaining the Relative Temperature Indices.

The statistical procedures outlined in IEEE Publication No. 101 were used in these determinations.

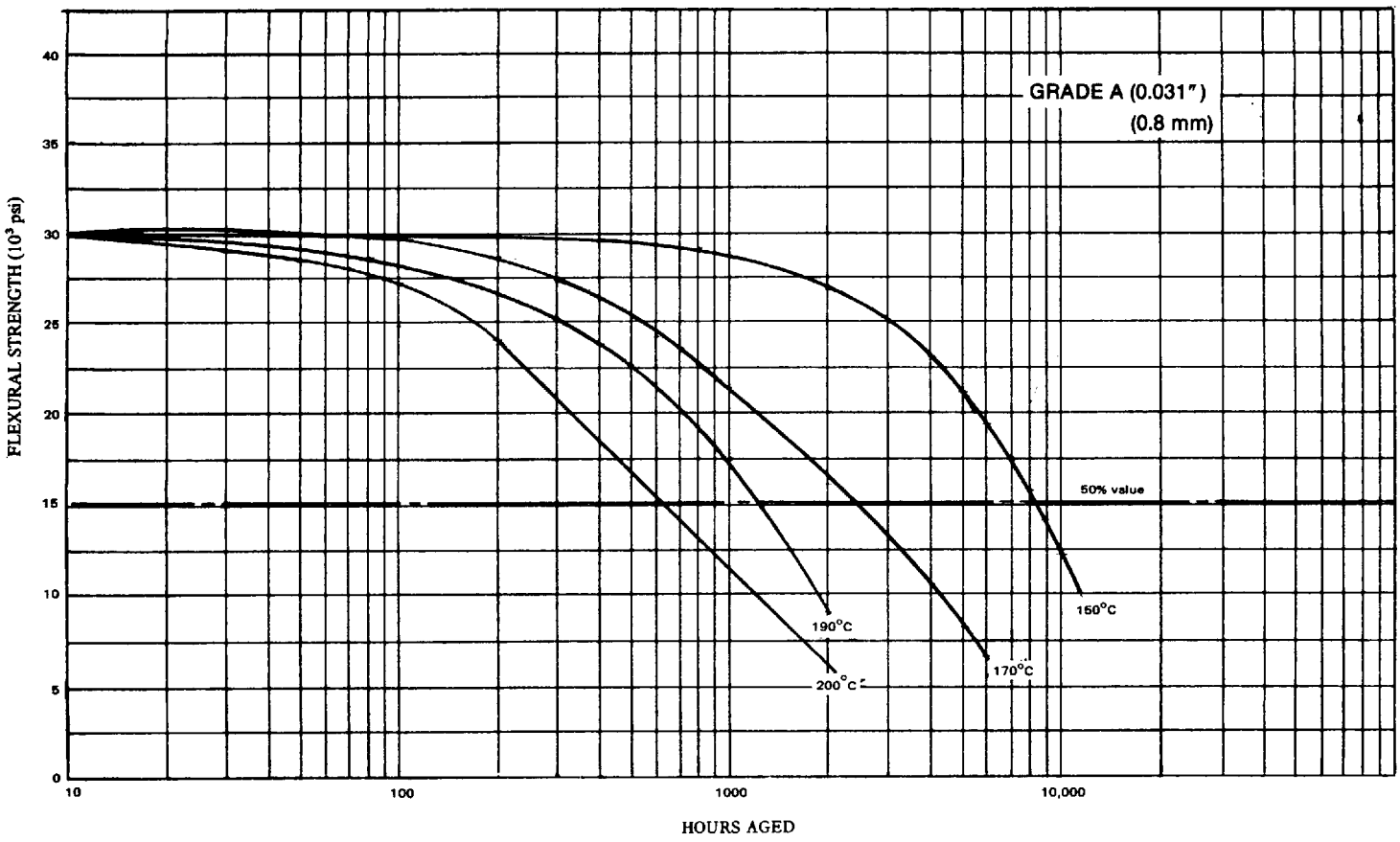
The relative temperature index was established for electrical and mechanical properties separately. Usually the end point of mechanical properties (flexural strength) was reached before the end point for electrical properties. For certain grades in which the electric strength reached its end-point first, tests were continued to determine the mechanical end-point.

Also, for grades whose data showed a significant difference between 0.031 inch (0.8 mm) and 0.06 inch (1.6 mm) thickness, different temperature indices were assigned for the different thicknesses. These temperature indices provide the designer with information which is useful in determining the primary requirement of the application.

Testing was continued at least until the property, either mechanical or electrical, had deteriorated to less than one-half of the unaged test value, the time at which one-half of the unaged test value was reached was considered the end-point for that grade at the temperature under consideration.

Underwriters Laboratories, Inc. Standard for Safety UL 746B is the present authority in the United States for procedures for testing solid electrical insulating materials to establish relative temperature indexes. Reference should be made to that publication for details of requirements for thermal-aging ovens, selection of aging temperatures, number of specimens, determination of end--of-life from test data by mathematical analysis, and the determination of relative temperature indexes by comparisons of the Arrhenius curve of a candidate material with that of the reference or control material.

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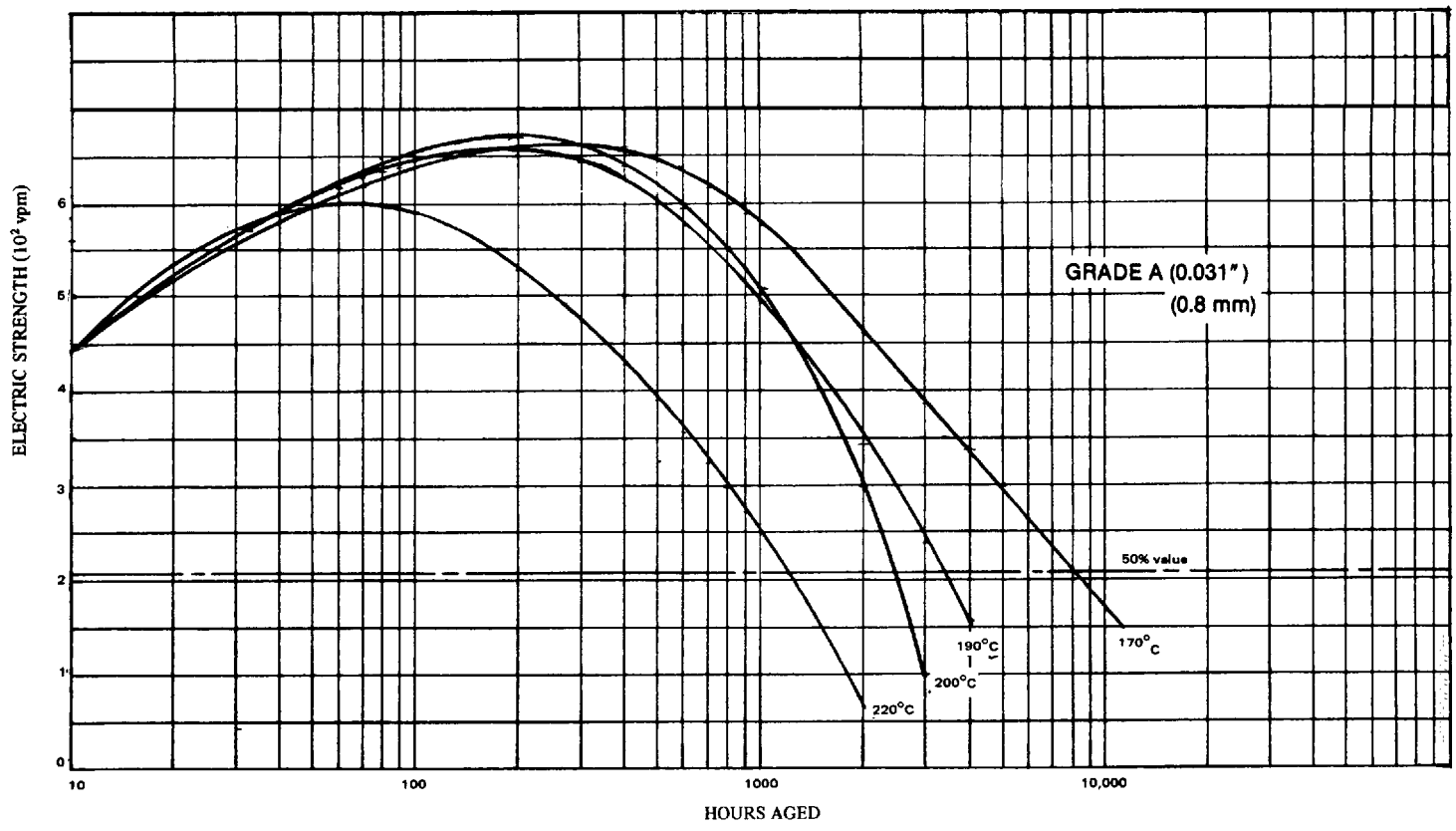


Figure 7-1
ILLUSTRATION OF DEGRADATION CURVES

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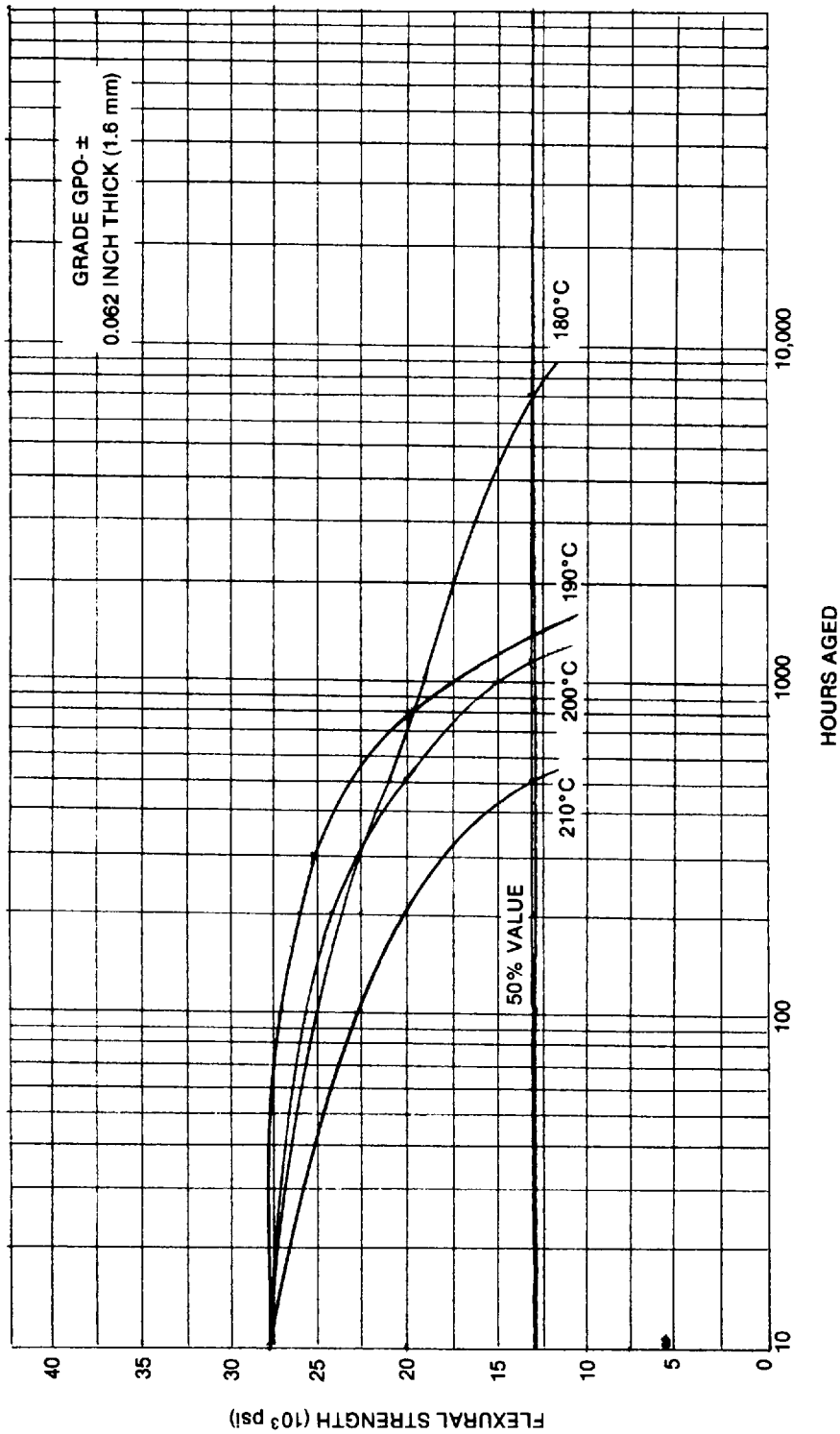


Figure 7-1a
FLEXURAL STRENGTH GRADE GPO-2

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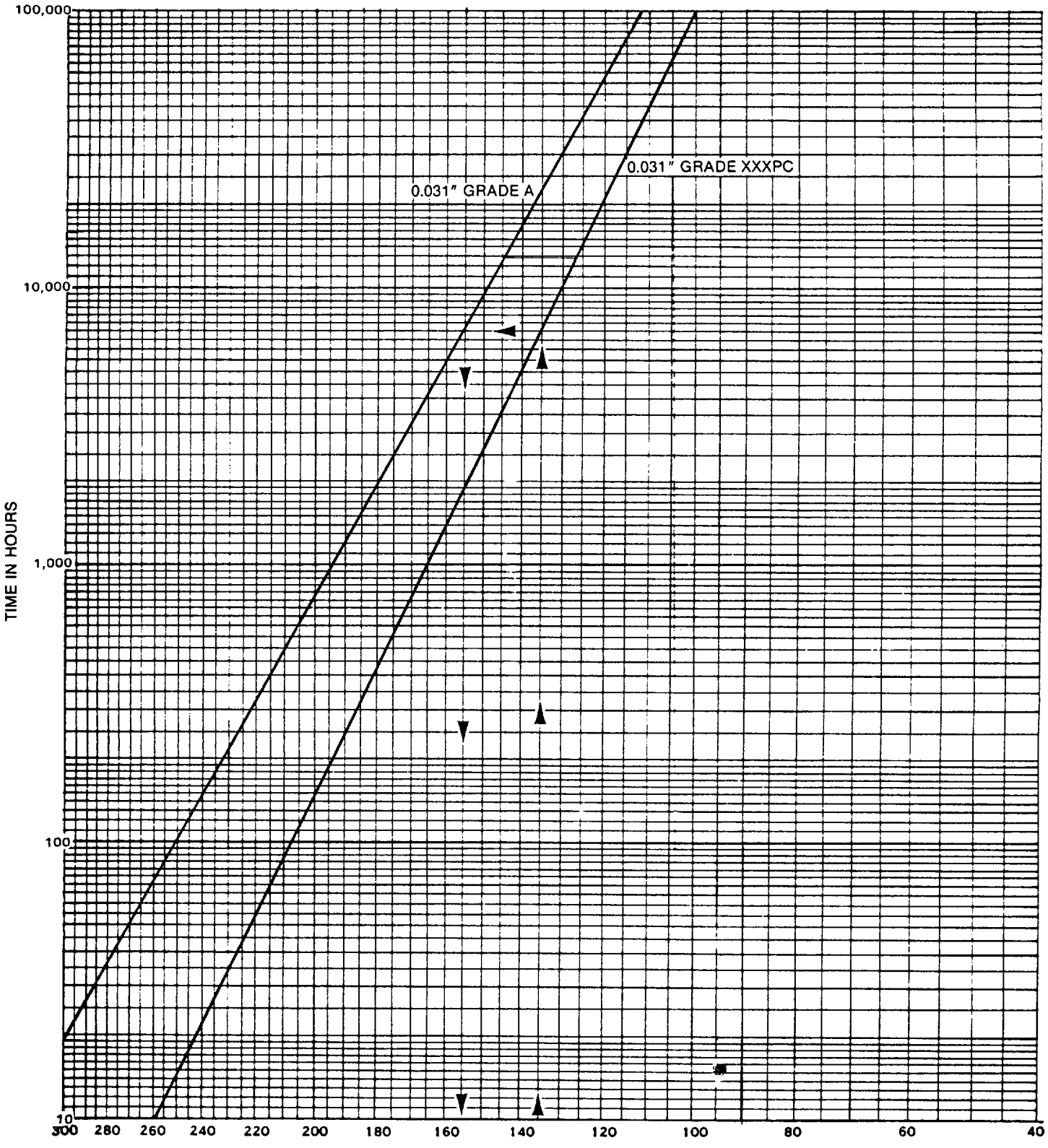


Figure 7-2
ILLUSTRATION OF RELATIVE TEMPERATURE INDEX DETERMINATION FOR FLEXURAL STRENGTH
0.031" (0.8 mm)

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APPENDIX A

Arrhenius curves for all grades tested are arranged as follows:

Grades Tested	Other Grades Represented	Property	Nominal Thickness Inch	mm	Page
XXXPC*	XXXP	Flexural Strength	0.062	1.6	A-1
		Flexural Strength	0.031	0.8	A-2
XP*	X, XPC	Flexural Strength	0.062	1.6	A-3
		Flexural Strength	0.031	0.8	A-4
XX*	XXP, XXX	Flexural Strength	0.062	1.6	A-5
		Flexural Strength	0.031	0.8	A-6
CE	C, L, LE	Flexural Strength	0.062	1.6	A-7
		Flexural Strength	0.031	0.8	A-8
		Electric Strength	0.062	1.6	A-9
		Electric Strength	0.031	0.8	A-10
FR-2		Flexural Strength	0.062	1.6	A-11
		Flexural Strength	0.031	0.8	A-12
FR-3		Flexural Strength	0.062	1.6	A-13
		Flexural Strength	0.031	0.8	A-14
FR-4	G-10	Flexural Strength	0.062	1.6	A-15
		Flexural Strength	0.031	0.8	A-16
		Electric Strength	0.062	1.6	A-17
		Electric Strength	0.031	0.8	A-18
A	AA	Flexural Strength	0.062	1.6	A-19
		Flexural Strength	0.031	0.8	A-20
		Electric Strength	0.062	1.6	A-21
		Electric Strength	0.031	0.8	A-22
G-3		Flexural Strength	0.062	1.6	A-23
		Flexural Strength	0.031	0.8	A-24
		Electric Strength	0.062	1.6	A-25
		Electric Strength	0.031	0.8	A-26
G-7		Flexural Strength	0.062	1.6	A-27
		Flexural Strength	0.031	0.8	A-28
		Electric Strength	0.062	1.6	A-29
		Electric Strength	0.031	0.8	A-30
G-9**	G-5**	Flexural Strength	0.062	1.6	A-31
		Flexural Strength	0.031	0.8	A-32
		Electric Strength	0.062	1.6	A-33
G-11	FR-5	Flexural Strength	0.062	1.6	A-34
		Flexural Strength	0.031	0.8	A-35
		Electric Strength	0.062	1.6	A-36
		Electric Strength	0.031	0.8	A-37
GPO-2		Flexural Strength	0.062	1.6	A-38
		Electric Strength	0.062	1.6	A-30
GPO-3		Flexural Strenght	0.062	1.6	A-40
		Electric Strength	0.062	1.6	A-41
CEM-1		Flexural Strength	0.062	1.6	A-42
		Flexural Strength	0.031	0.8	A-43
	CEM-3	Electric Strength	0.062	1.6	A-44
		Electric Strength	0.031	0.8	A-45
CEM-3		Flexural Strength	0.062	1.6	A-46
		Flexural Strength	0.031	0.8	A-47

* No electric strength curves are given for these grades because the electric strength did not deteriorate to the 50% level at the aging temperature selected.

** This grade is not for electrical applications.

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Grades XXXPC and XXXP
Flexural Strength
Arrhenius Curve at 50% of Original Strength
0.062 Inch (1.6 mm)

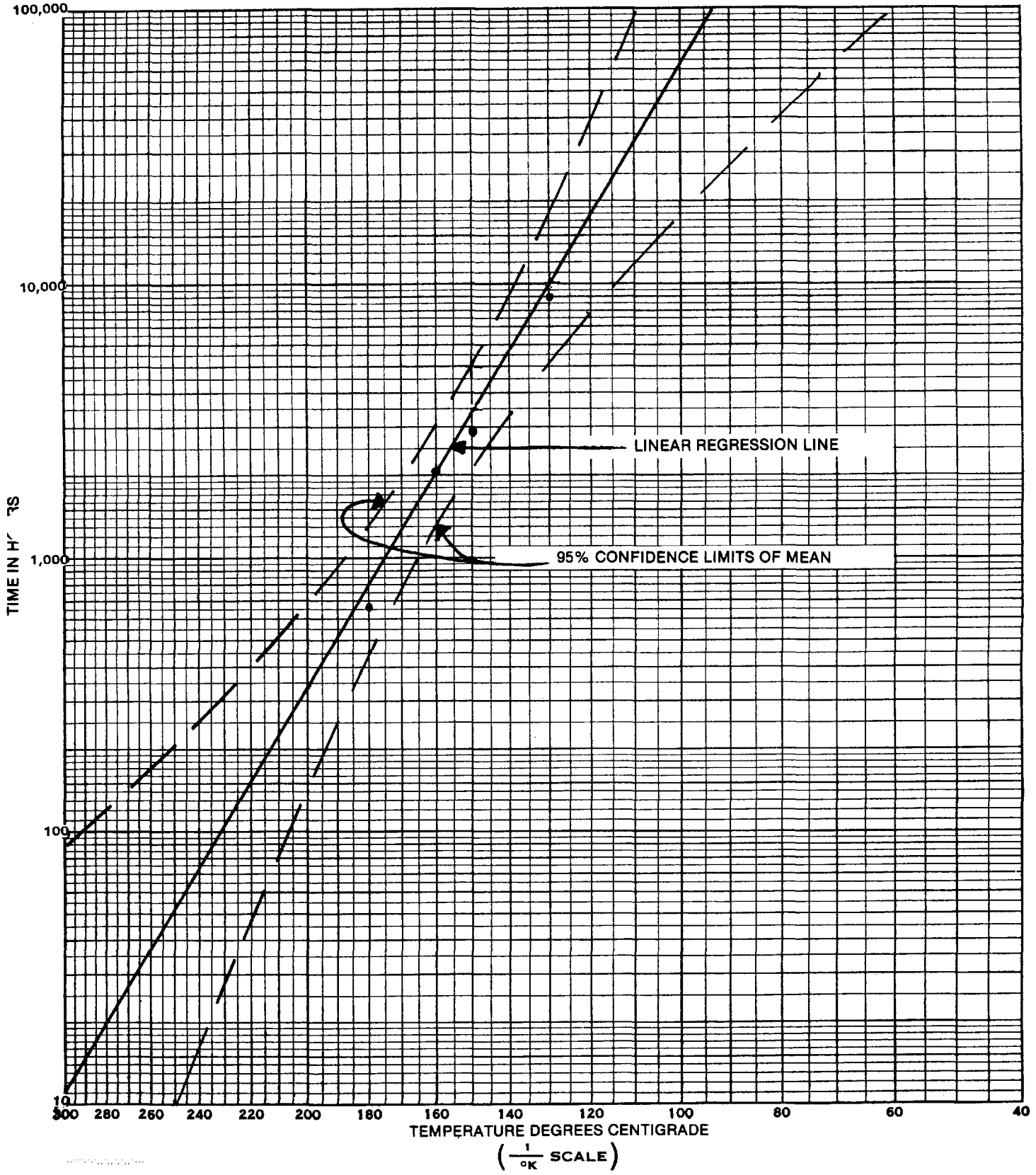


Figure A-1

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Grades XXXPC and XXXP
Flexural Strength
Arrhenius Curve at 50% of Original Strength
0.031 Inch (0.8 mm)

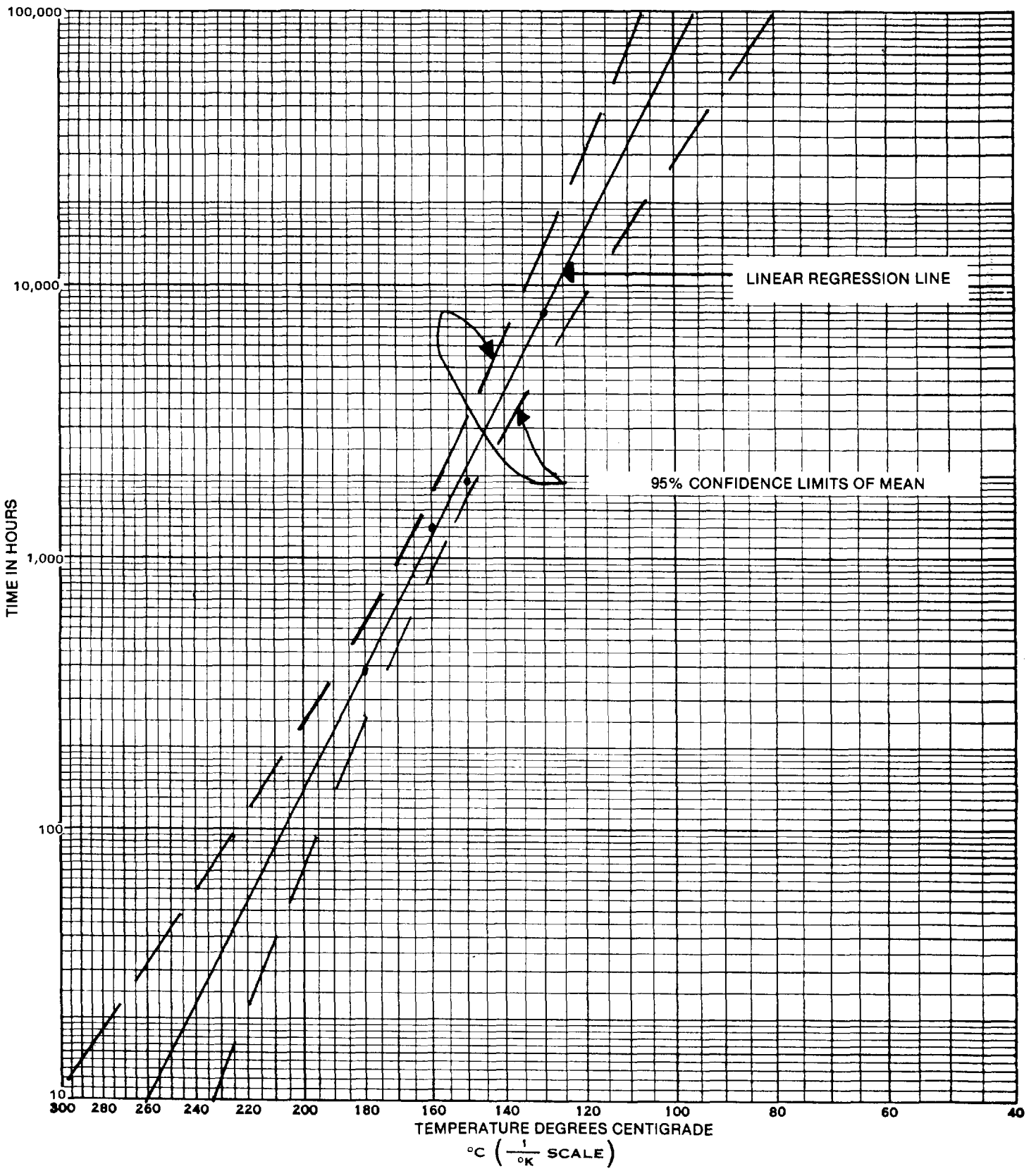


Figure A-2

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Grades XP, X, and XPC
Flexural Strength
Arrhenius Curve at 50% of Original Strength
0.031 Inch (0.8 mm)

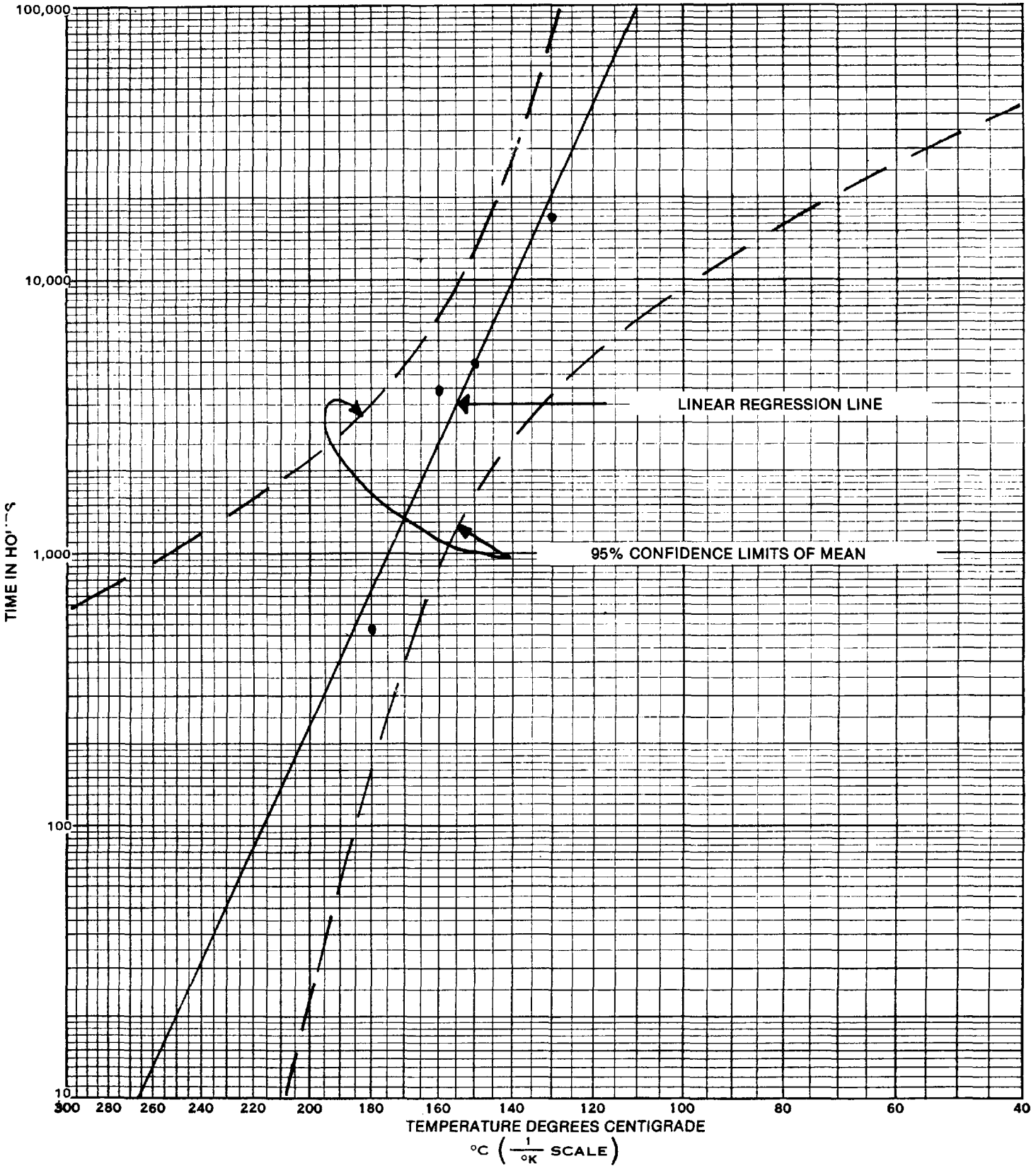


Figure A-3

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Grades XP, X, and XPC
Flexural Strength
Arrhenius Curve at 50% of Original Strength
0.031 Inch (0.8 mm)

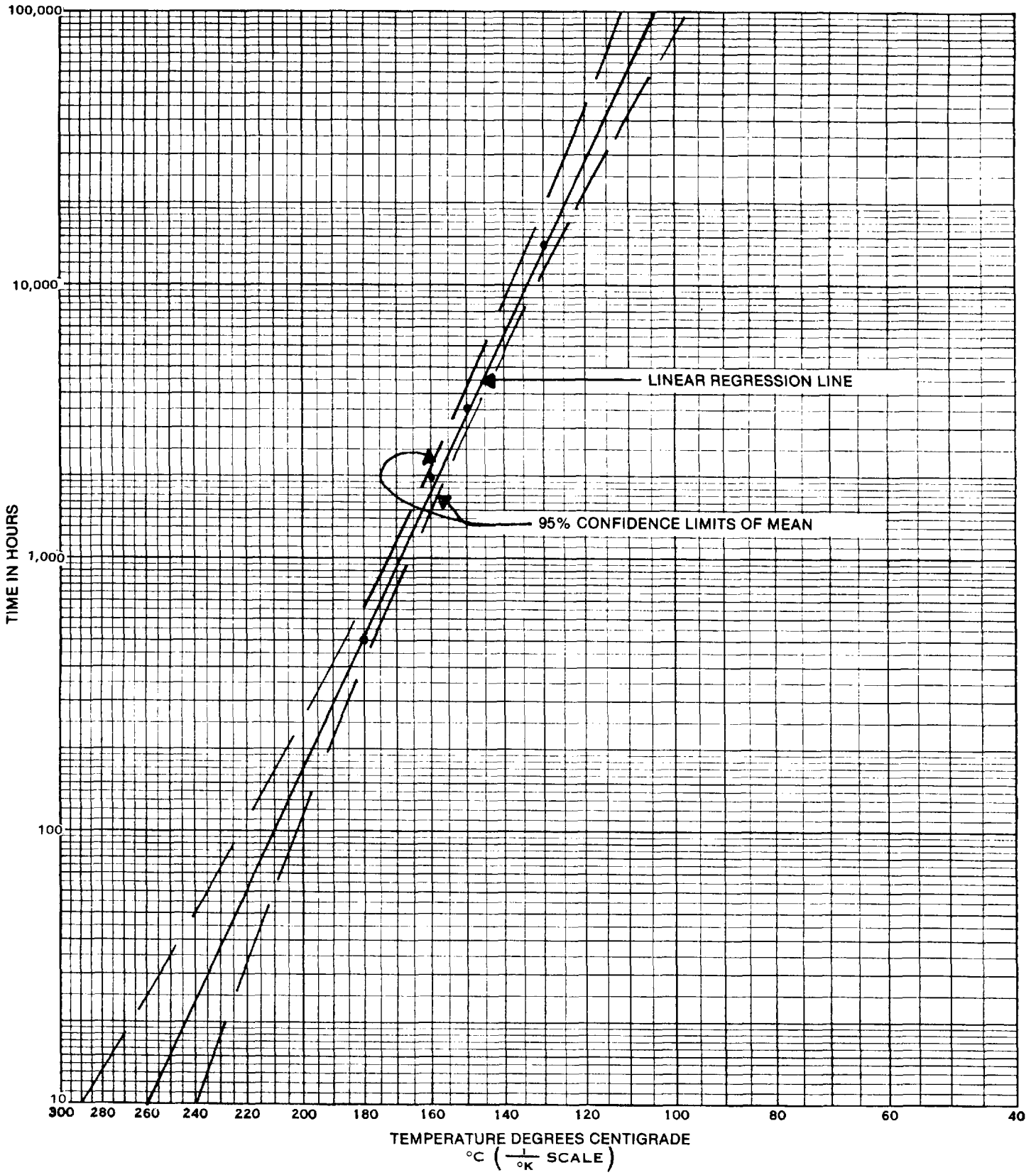


Figure A-4

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LI 6-1993
Page 24

Grades XX, XXP, and XXX
Flexural Strength
Arrhenius Curve at 50% of Original Strength
0.062 Inch (1.6 mm)

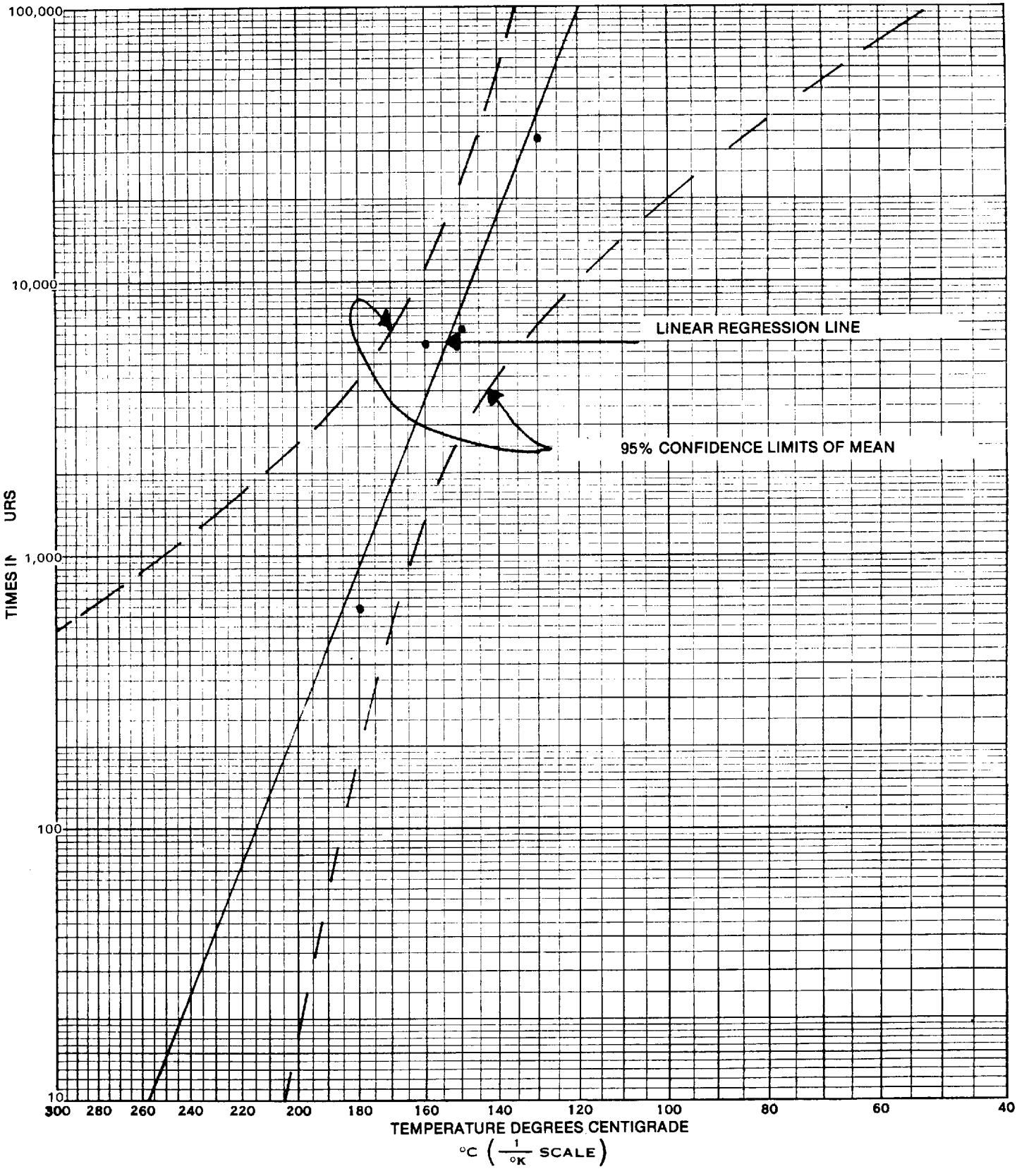


Figure A-5

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Grades XX, XXP and XXX
Flexural Strength
Arrhenius Curve at 50% of Original Strength
0.031 Inch (0.8 mm)

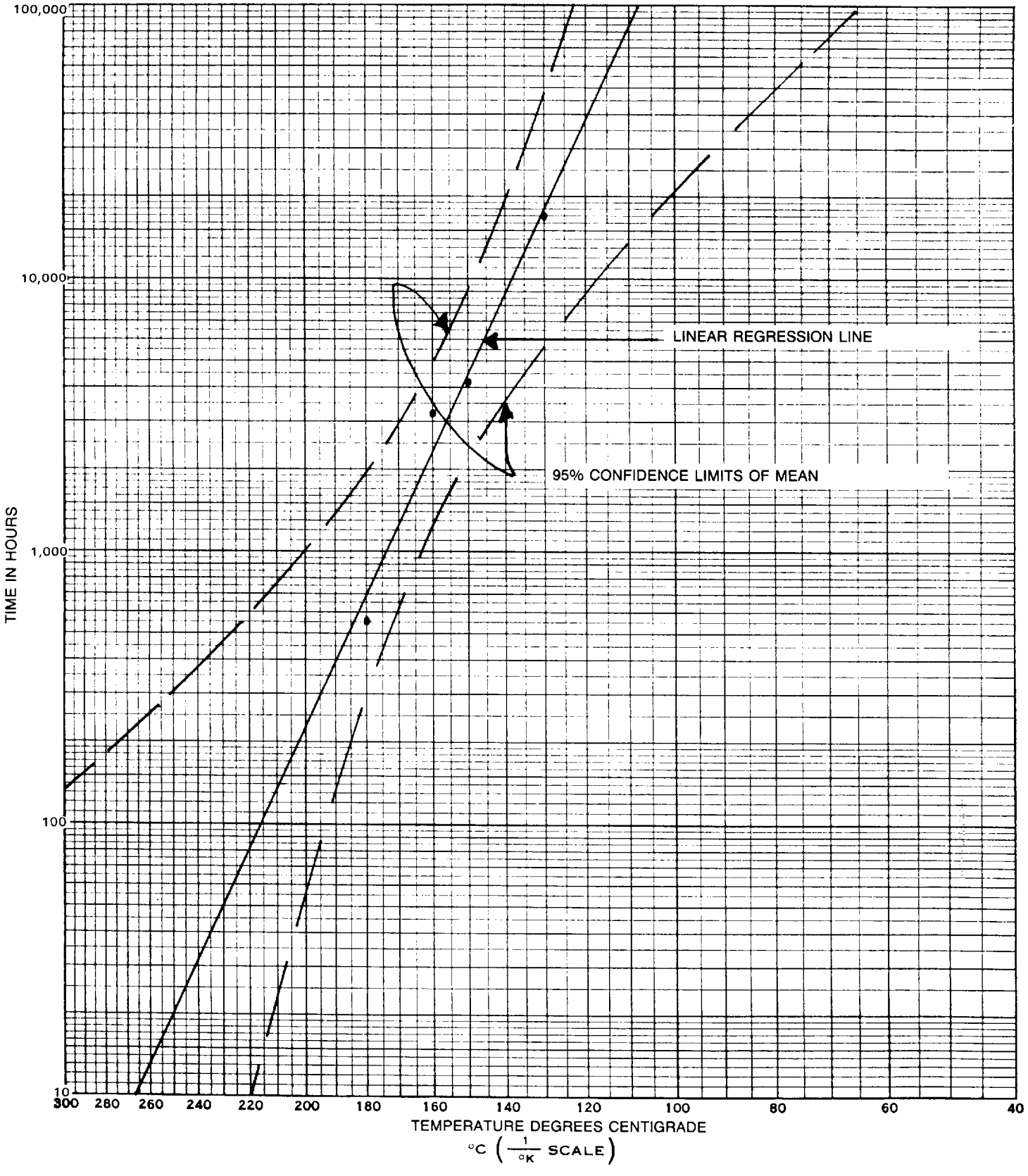


Figure A-6

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Grades CE, C, L and LE
Flexural Strength
Arrhenius Curve at 50% of Original Strength
0.062 Inch (0.6 mm)

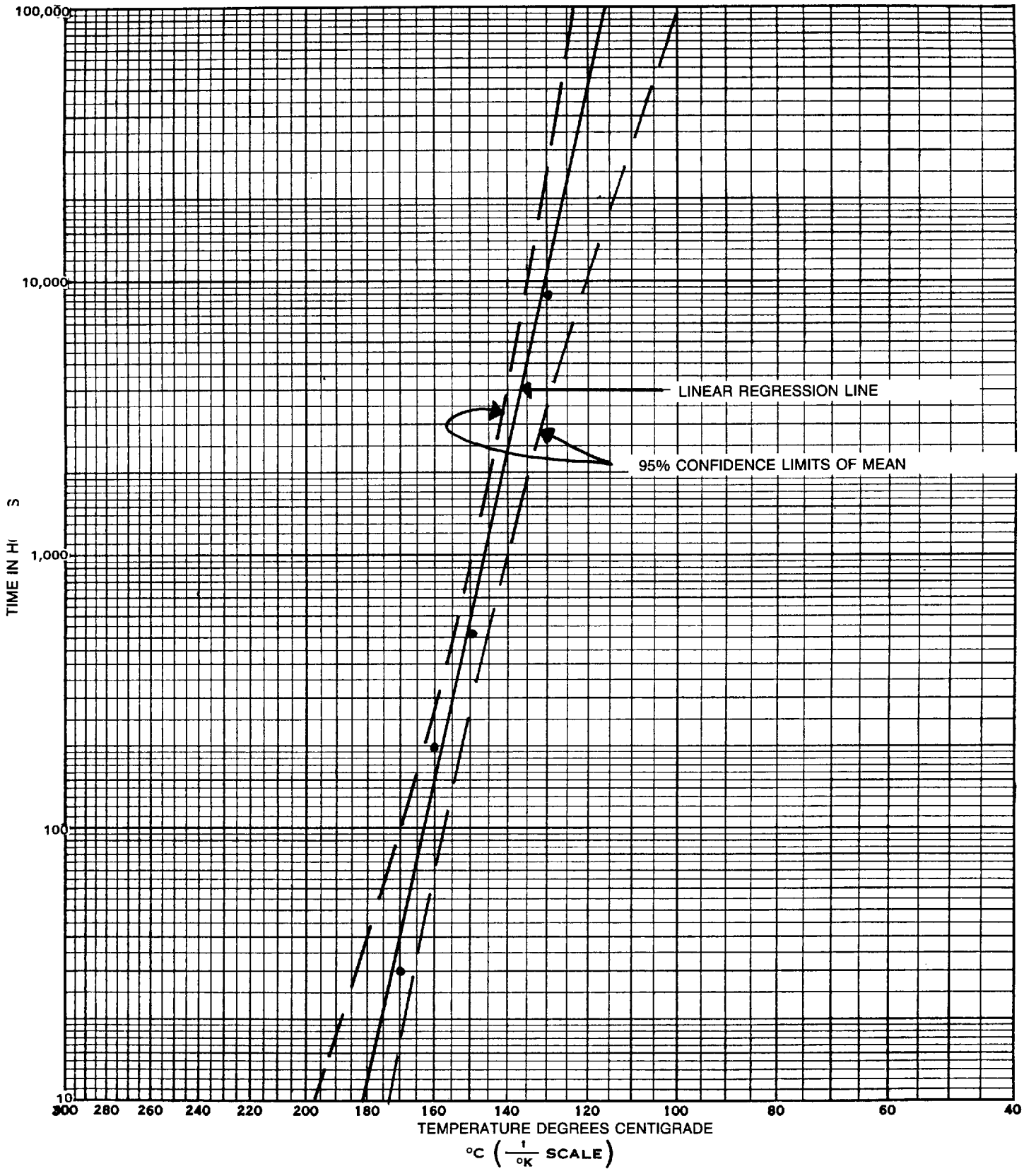


Figure A-7

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Grades CE, C, L and LE
Flexural Strength
Arrhenius Curve at 50% of Original Strength
0.031 Inch (0.8 mm)
(See Note 2 in Section 5)

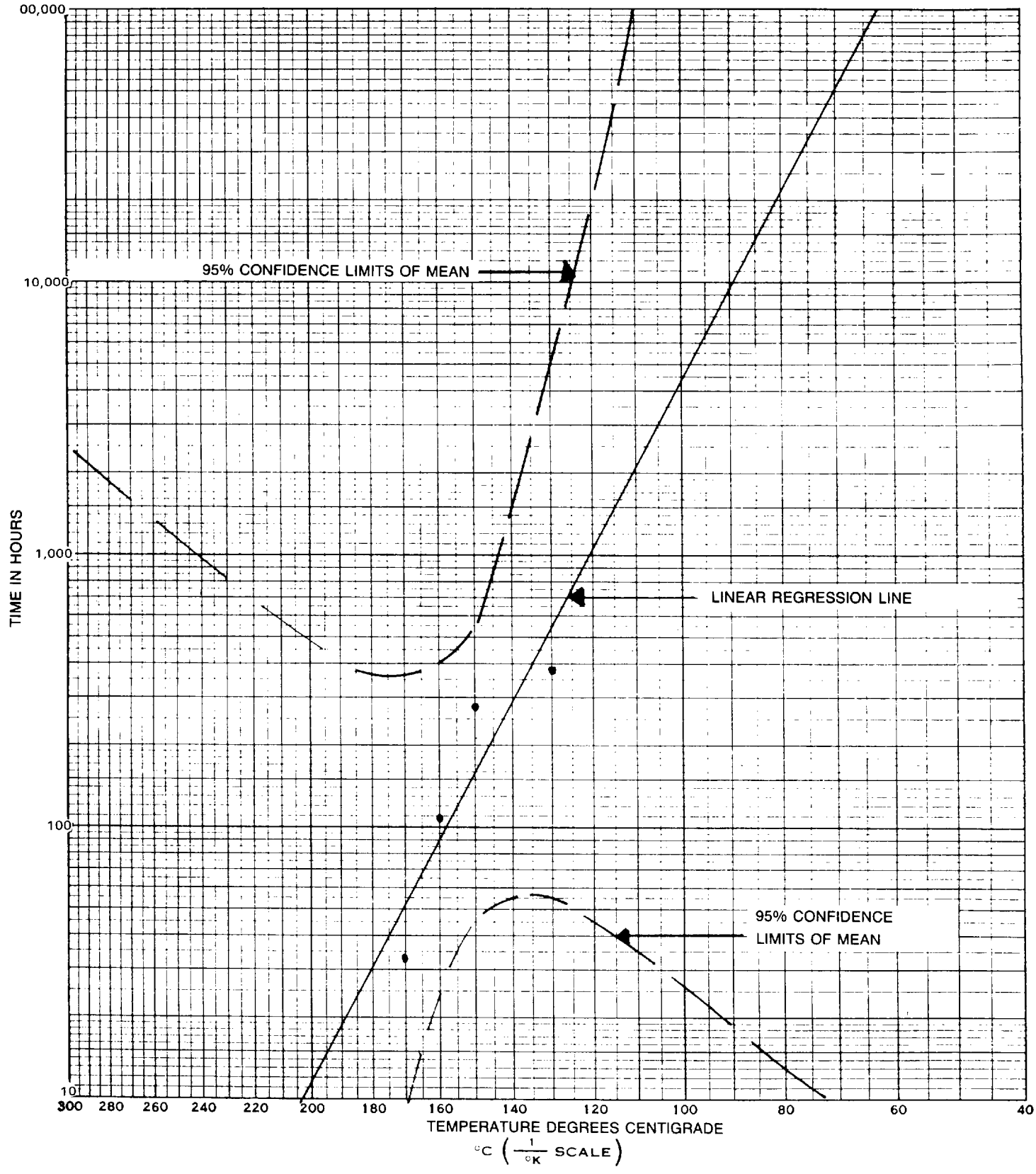


Figure A-8

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Not for Resale

Grades CE, C, L and LE
Electric Strength
Arrhenius Curve at 50% of Original Strength
0.062 Inch (0.6 mm)

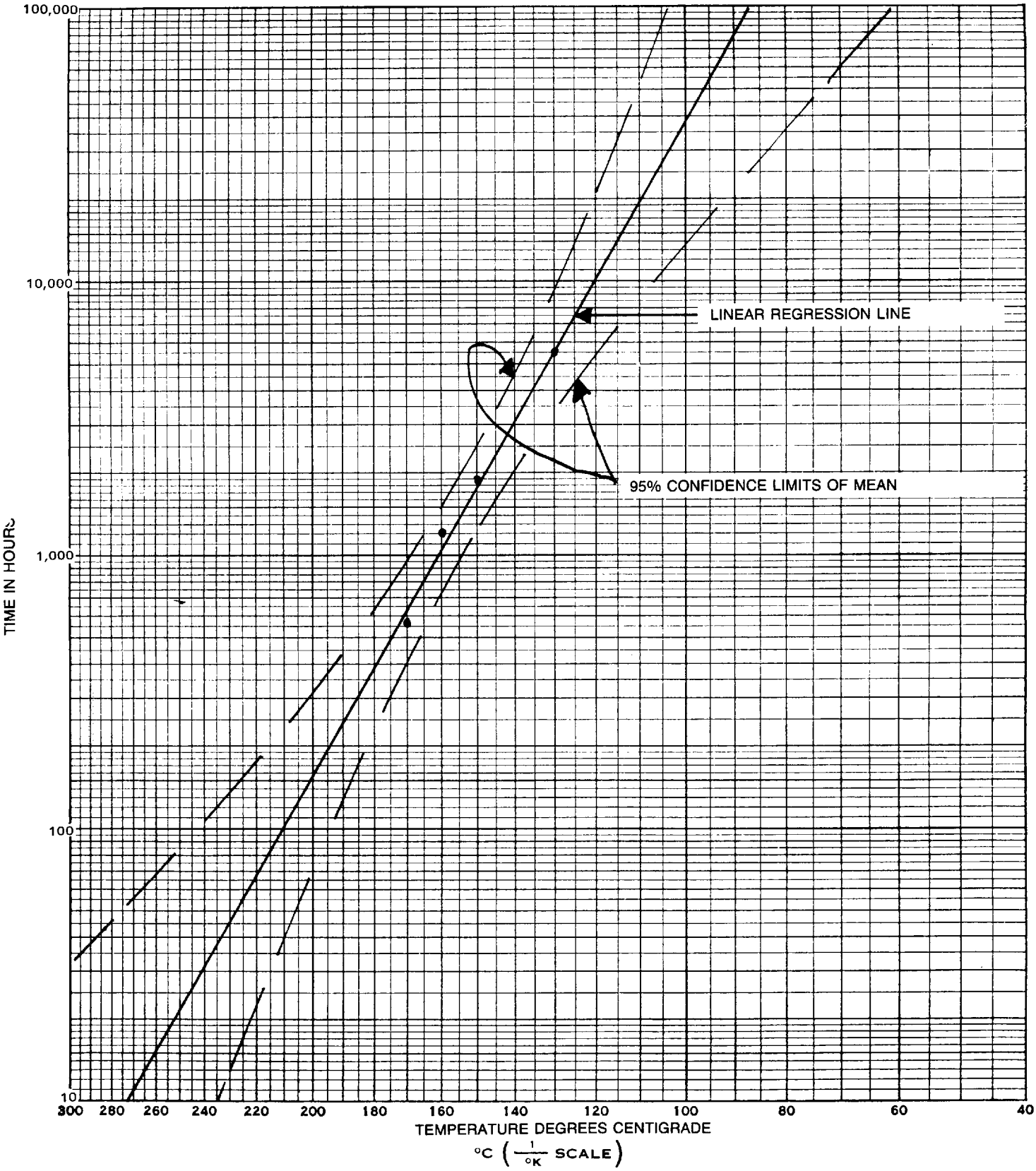


Figure A-9

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Grades CE, C, L and LE
Electric Strength
Arrhenius Curve at 50% of Original Strength
0.031 Inch (0.8 mm)

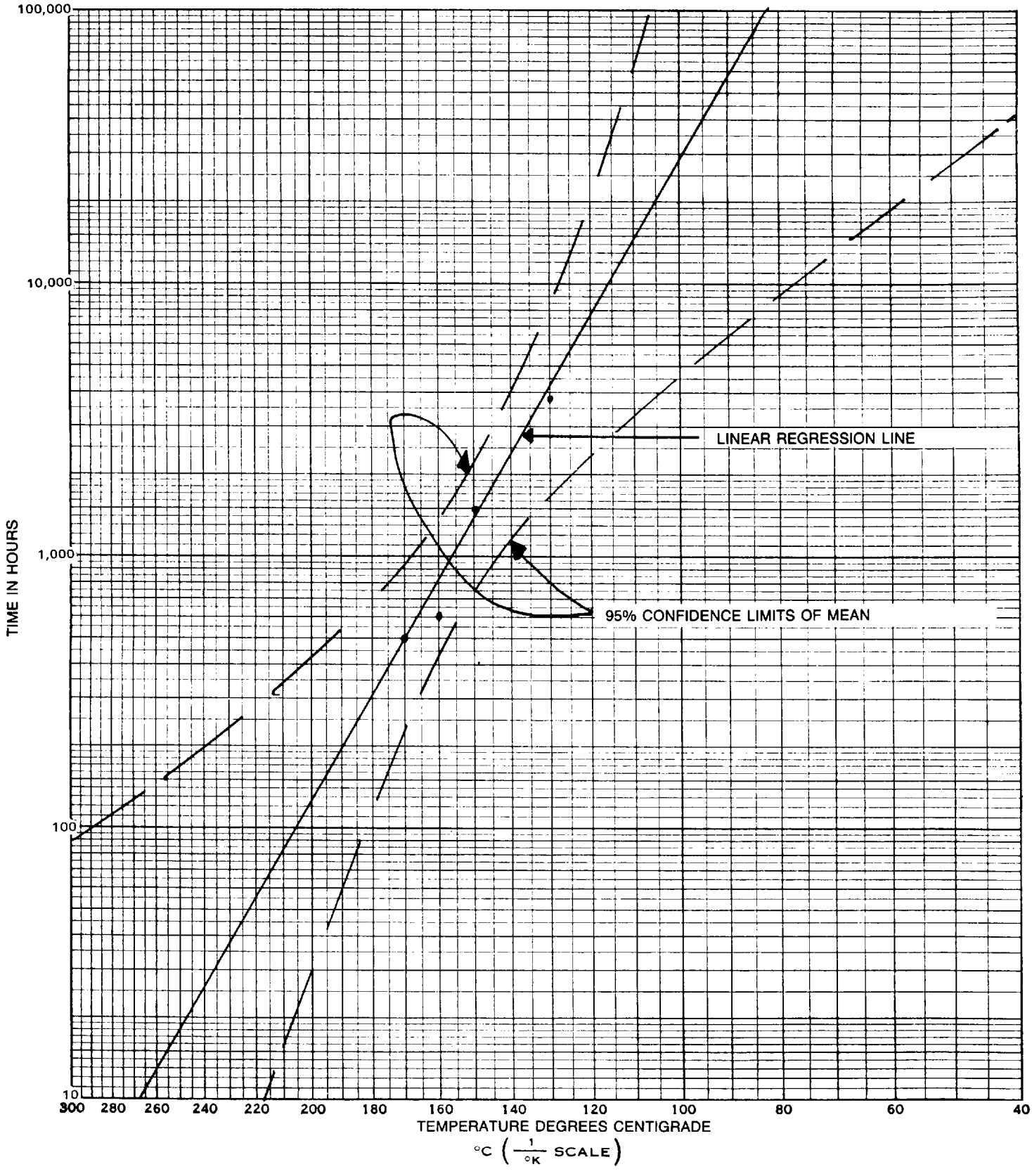


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Grade FR-2
Flexural Strength
Arrhenius Curve at 50% of Original Strength
0.062 Inch (0.6 mm)

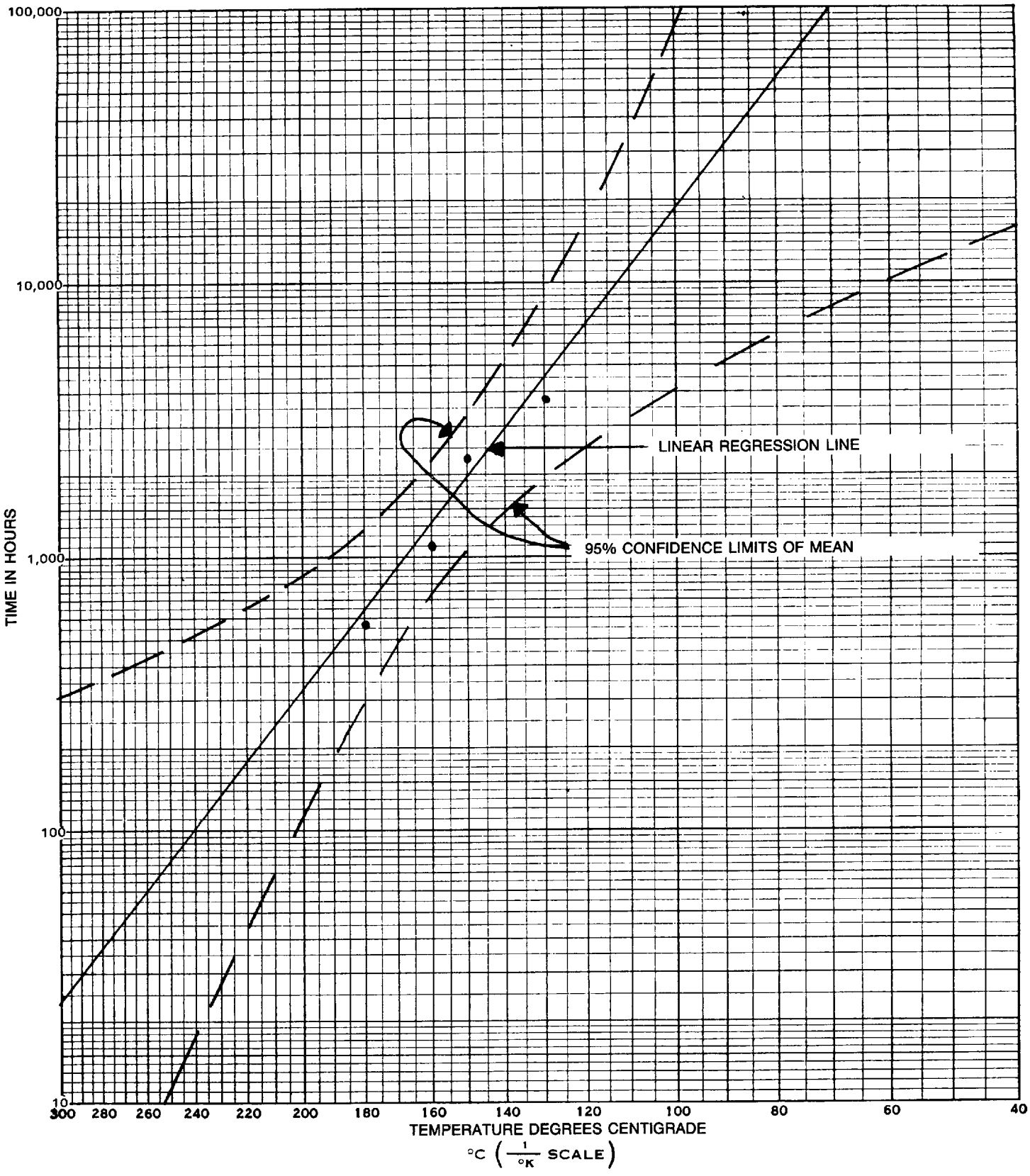


Figure A-11

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Grade FR-2
Flexural Strength
Arrhenius Curve at 50% of Original Strength
0.031 Inch (0.8 mm)

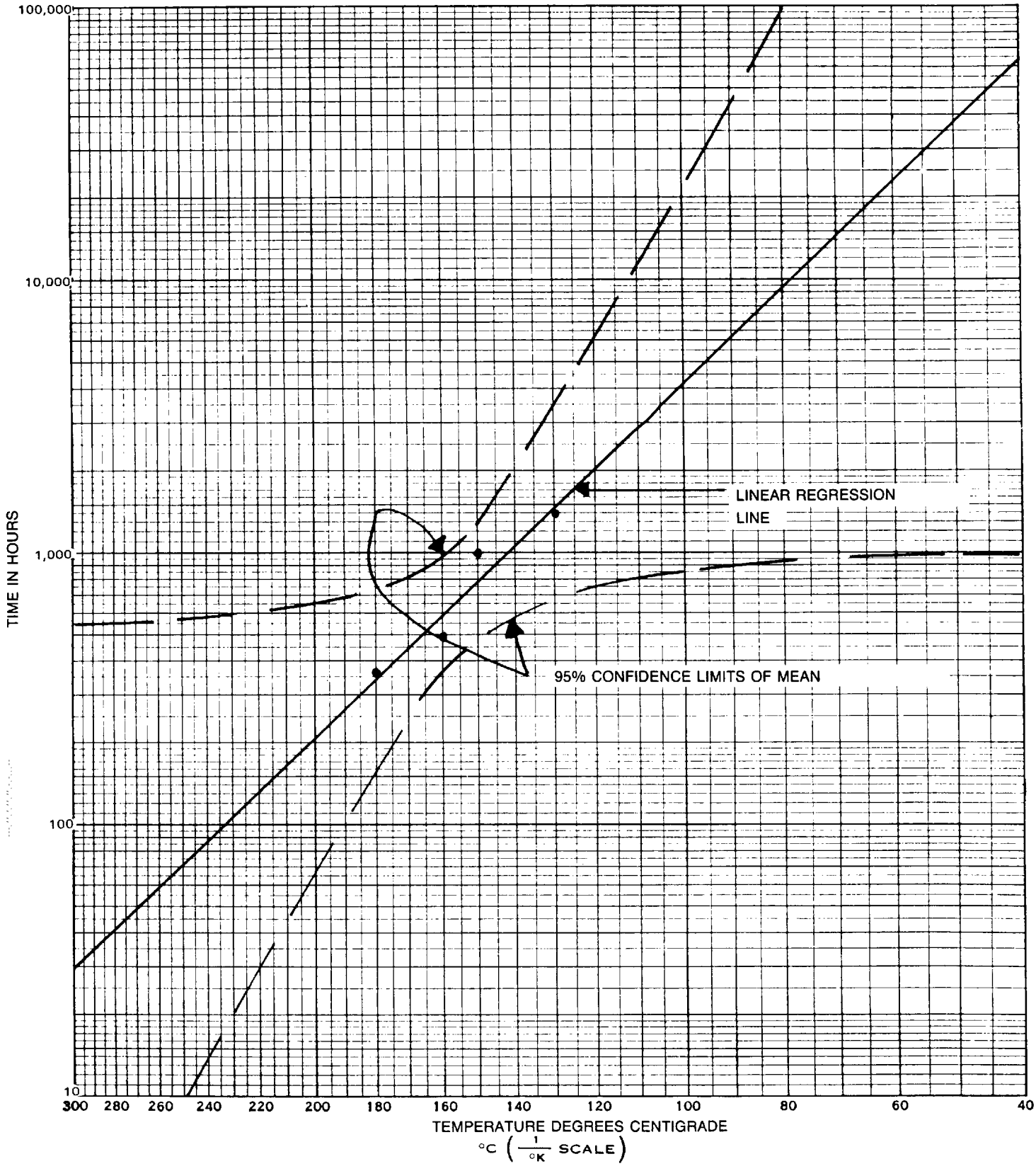


Figure A-12

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Grade FR-3
Flexural Strength
Arrhenius Curve at 50% of Original Strength
0.062 Inch (0.6 mm)

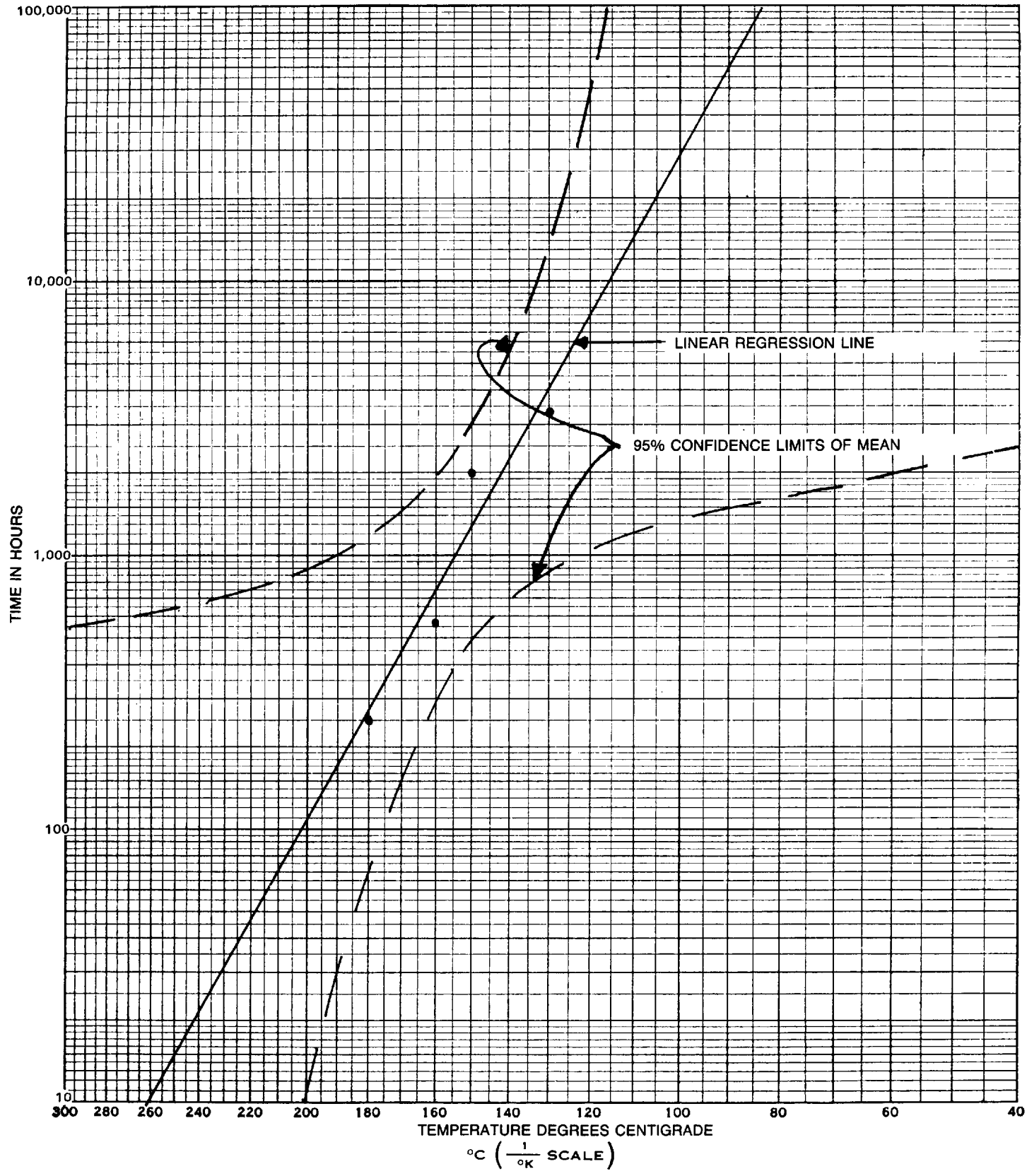


Figure A-13

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Grade FR-3
Flexural Strength
Arrhenius Curve at 50% of Original Strength
0.031 Inch (0.8 mm)
(See Note 2 in Section 5)

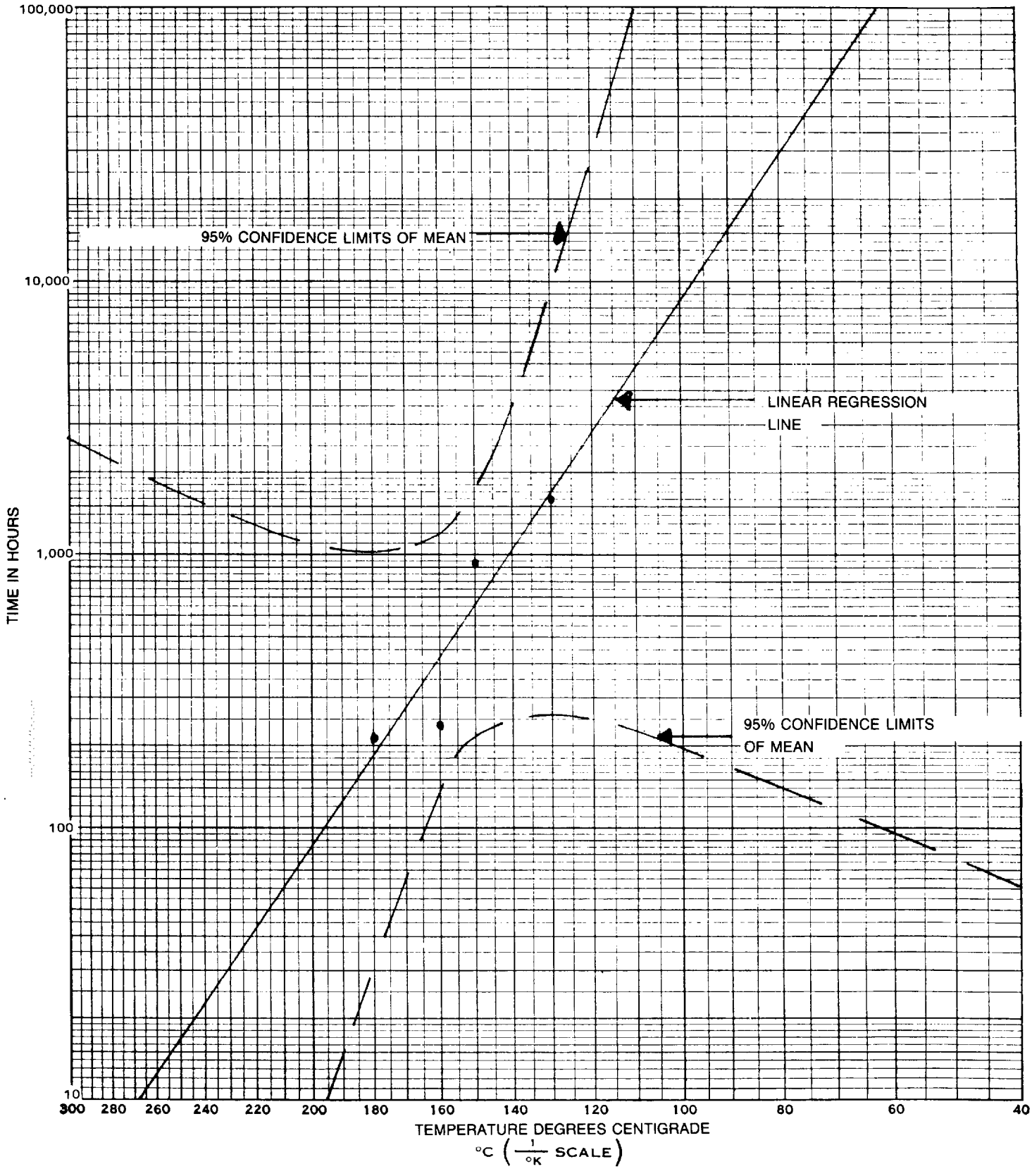


Figure A-14

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Grades FR-4 and G-10
Flexural Strength
Arrhenius Curve at 50% of Original Strength
0.062 Inch (0.6 mm)

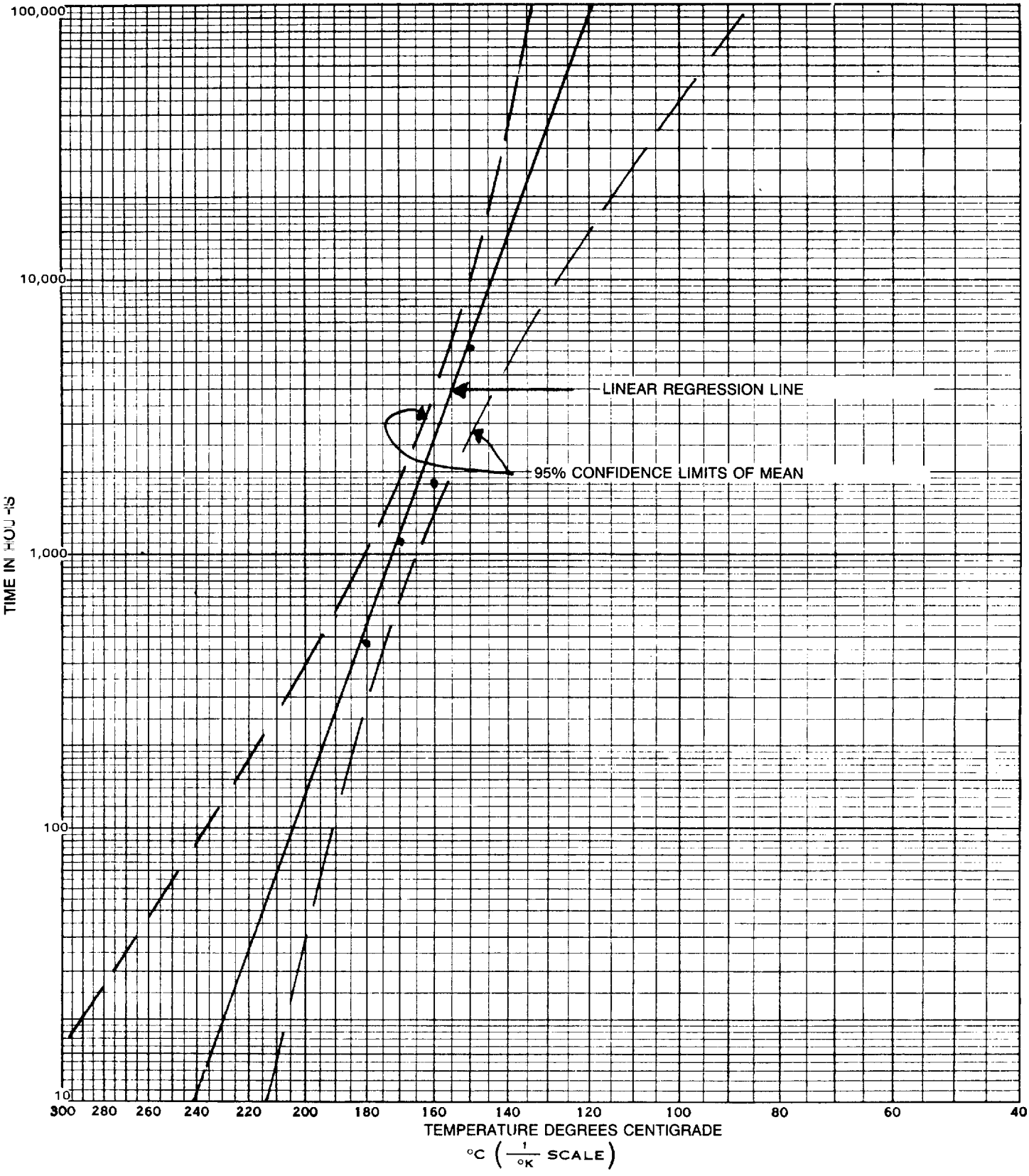


Figure A-15

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Grades FR-4 and G-10
Flexural Strength
Arrhenius Curve at 50% of Original Strength
0.031 Inch (0.8 mm)

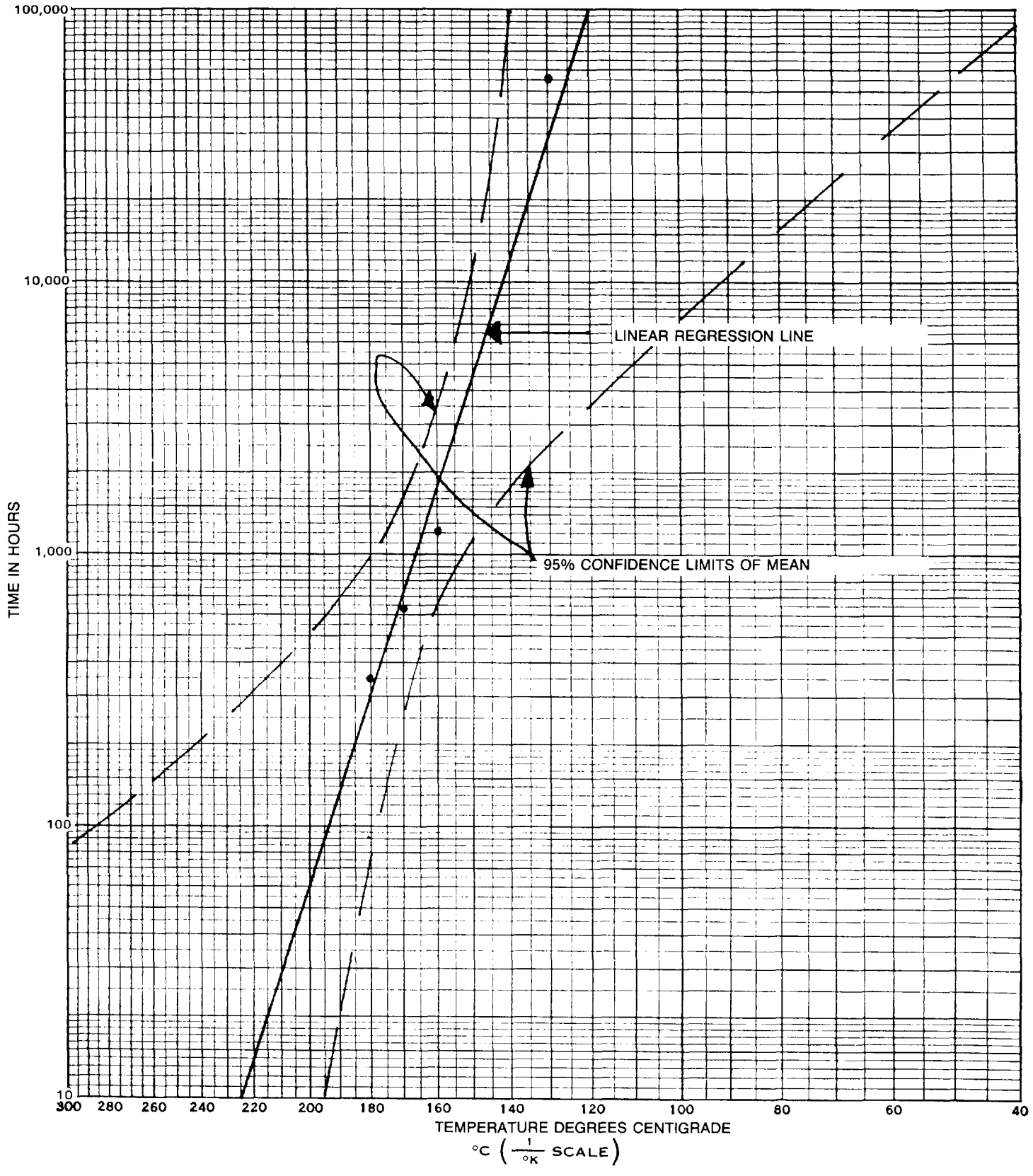


Figure A-16

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Not for Resale

Grade FR-4 and G-10
Electric Strength
Arrhenius Curve at 50% of Original Strength
0.062 Inch (0.6 mm)

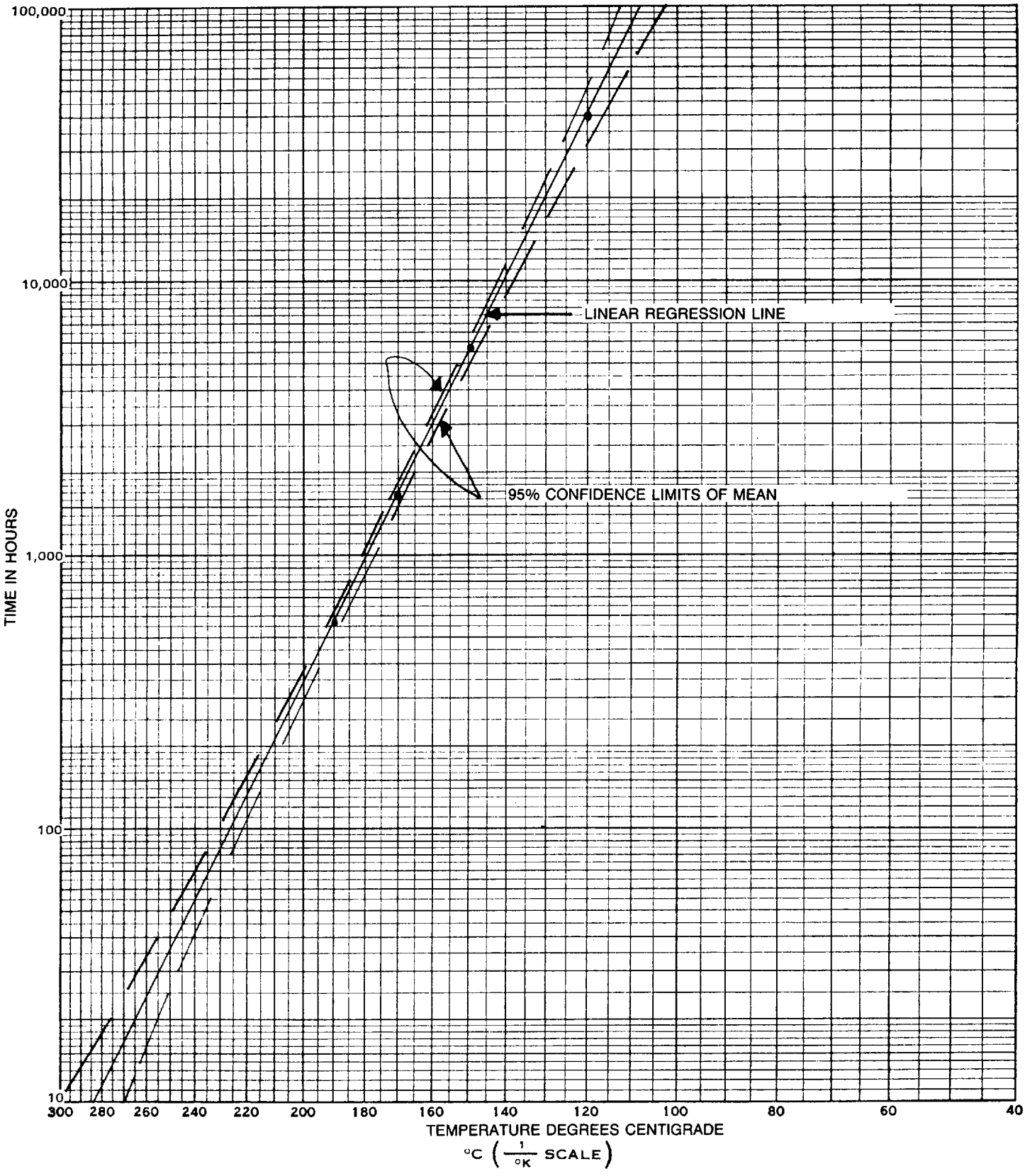


Figure A-17

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Grade FR-4 and G-10
Electric Strength
Arrhenius Curve at 50% of Original Strength
0.031 Inch (0.8 mm)

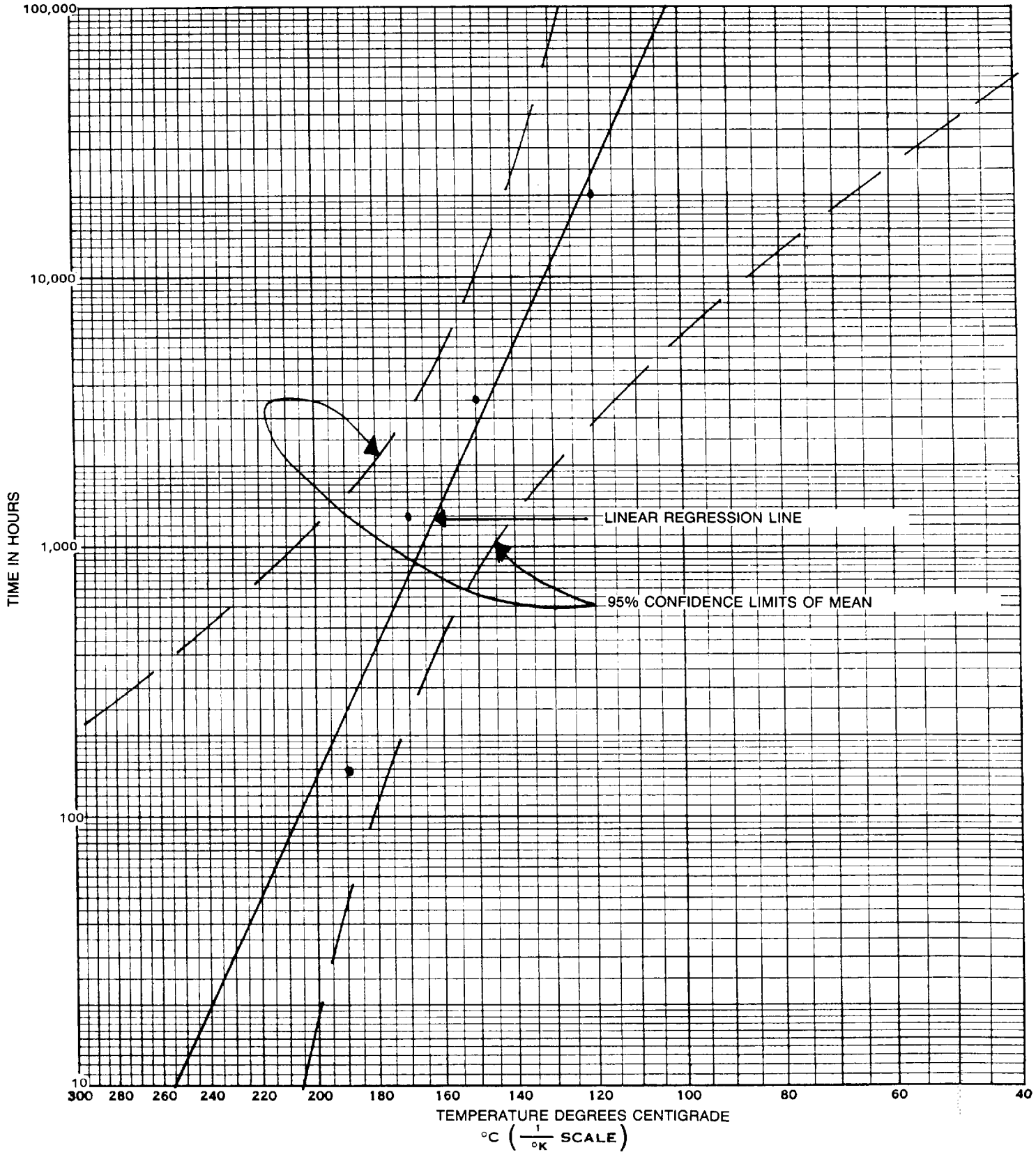


Figure A-18

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Grades A and AA
Flexural Strength
Arrhenius Curve at 50% of Original Strength
0.062 Inch (0.6 mm)

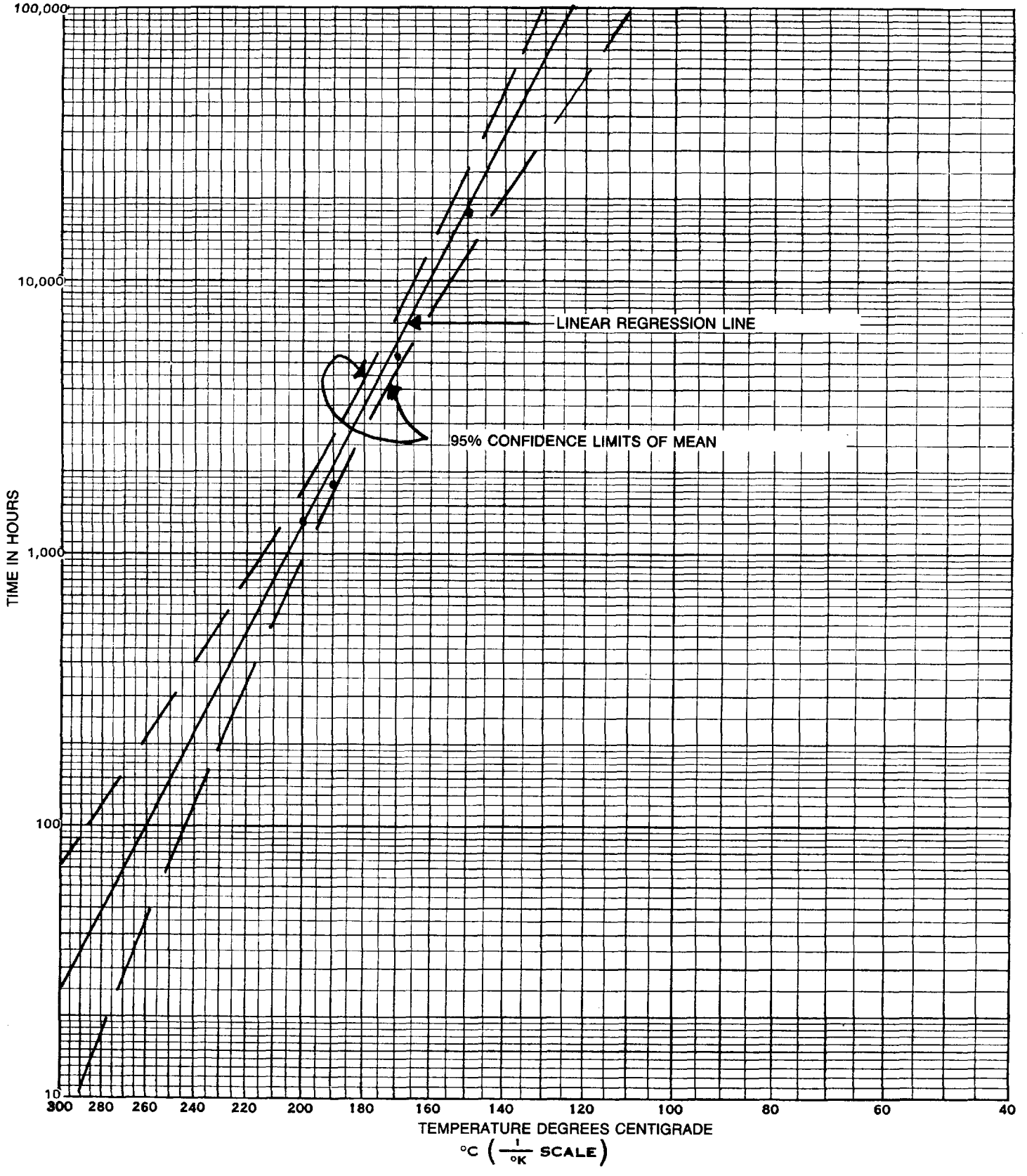


Figure A-19

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Grades A and AA
Flexural Strength
Arrhenius Curve at 50% of Original Strength
0.031 Inch (0.8 mm)

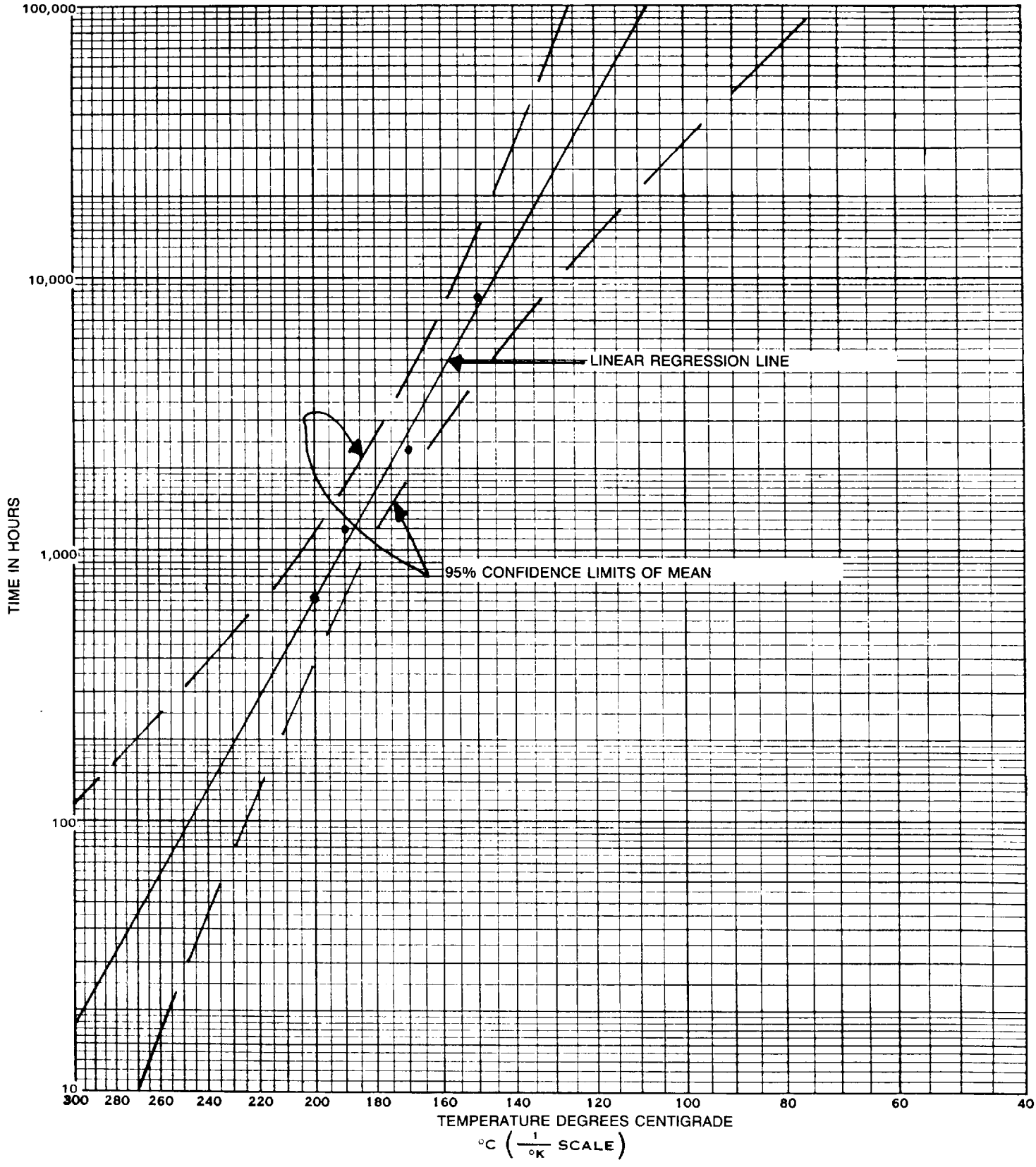


Figure A-20

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Grades A and AA
Electric Strength
Arrhenius Curve at 50% of Original Strength
0.062 Inch (0.6 mm)

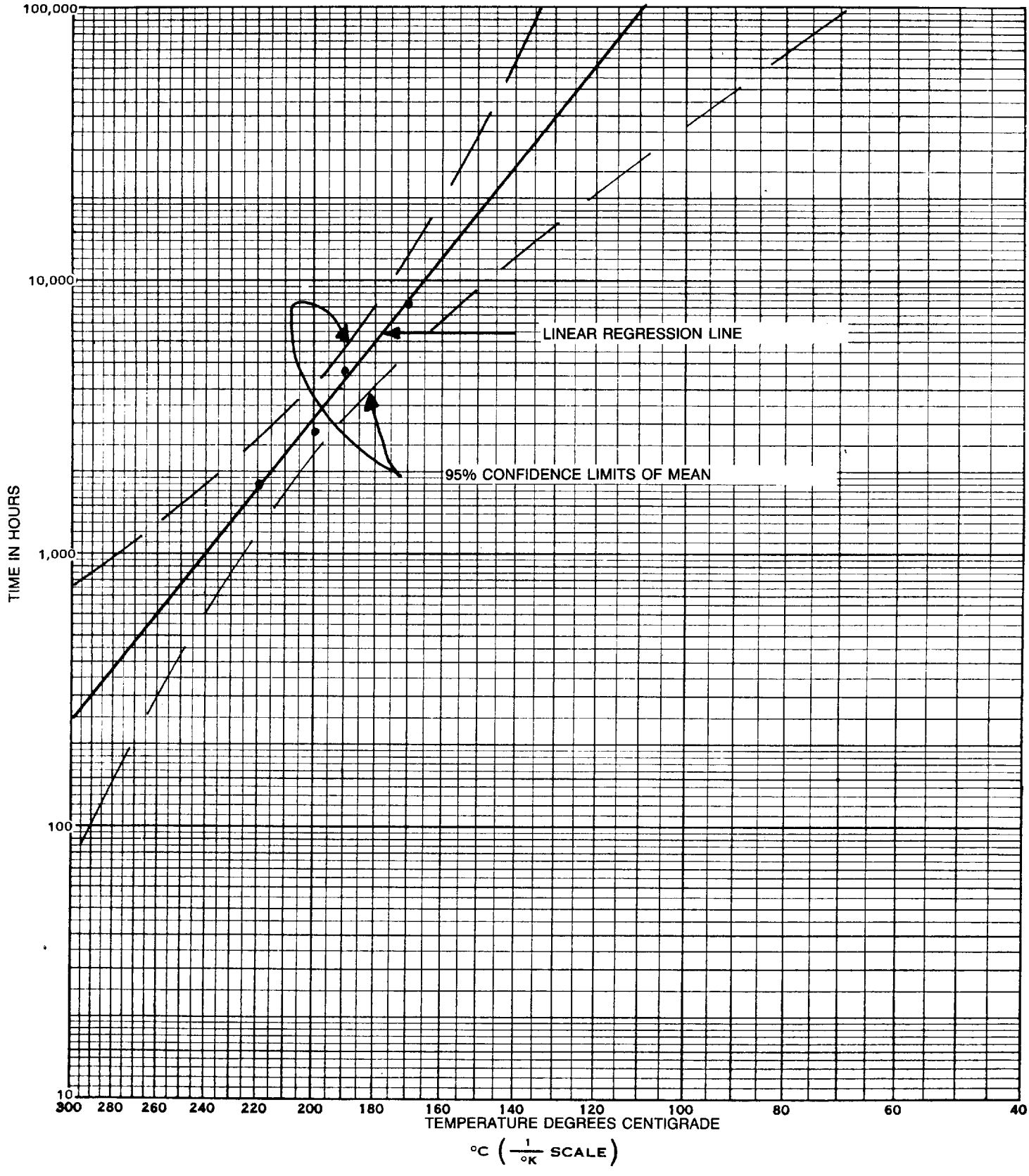


Figure A-21

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Grades A and AA
Electric Strength
Arrhenius Curve at 50% of Original Strength
0.031 Inch (0.8 mm)

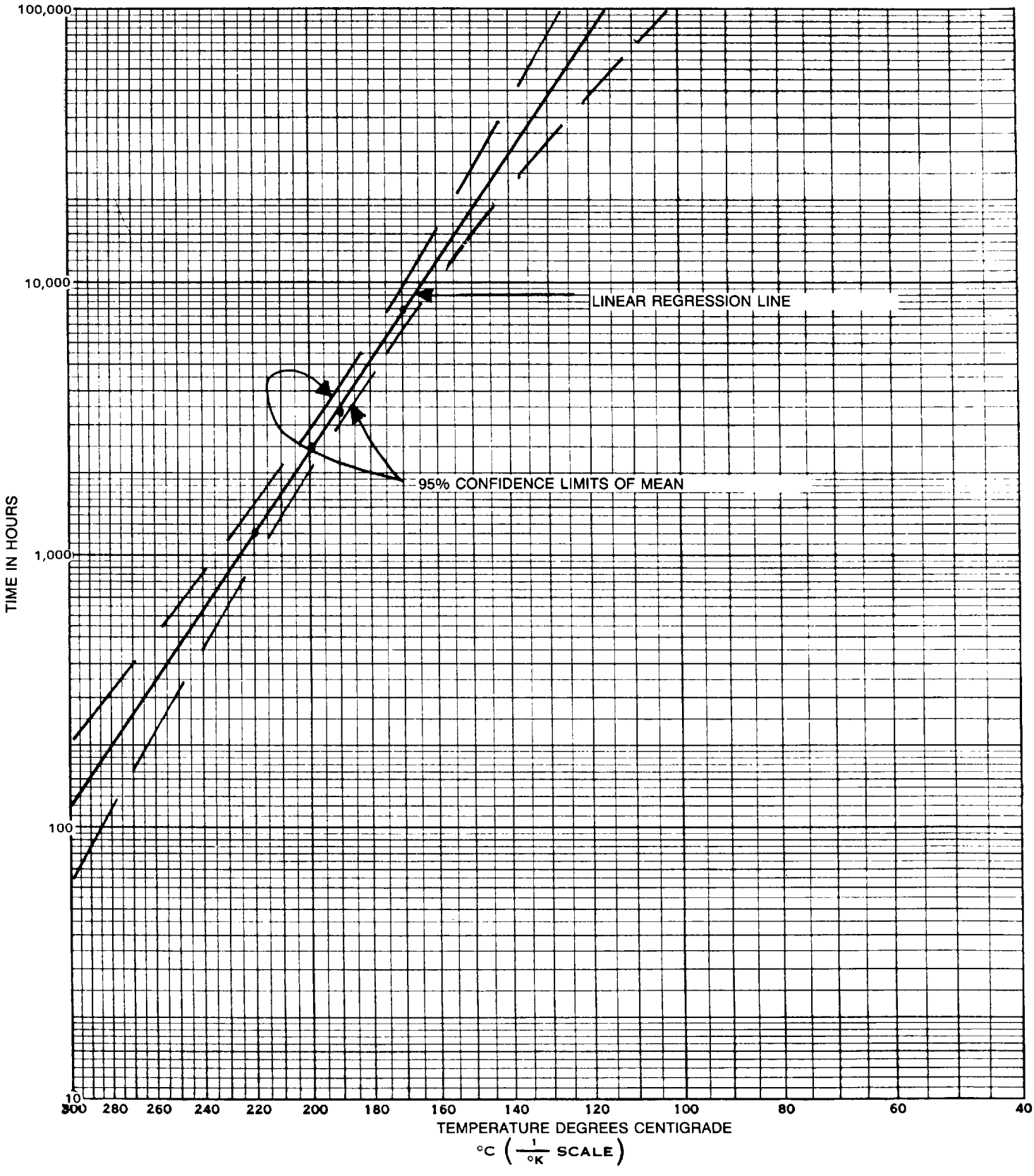


Figure A-22

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Grade G-3
Flexural Strength
Arrhenius Curve at 50% of Original Strength
0.062 Inch (0.6 mm)

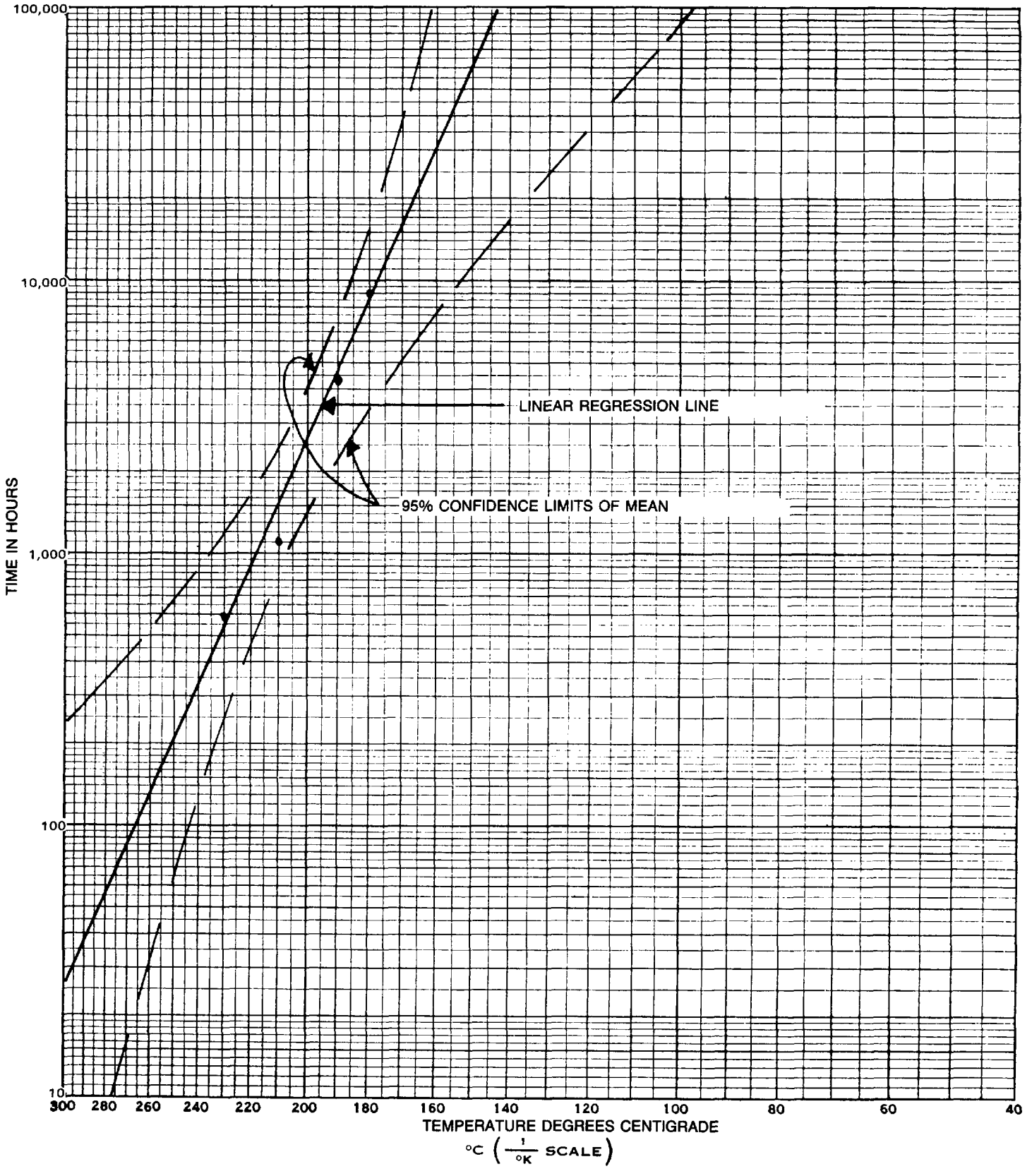


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Grade G-3
Flexural Strength
Arrhenius Curve at 50% of Original Strength
0.031 Inch (0.8 mm)
(See Note 2 on Page 6)

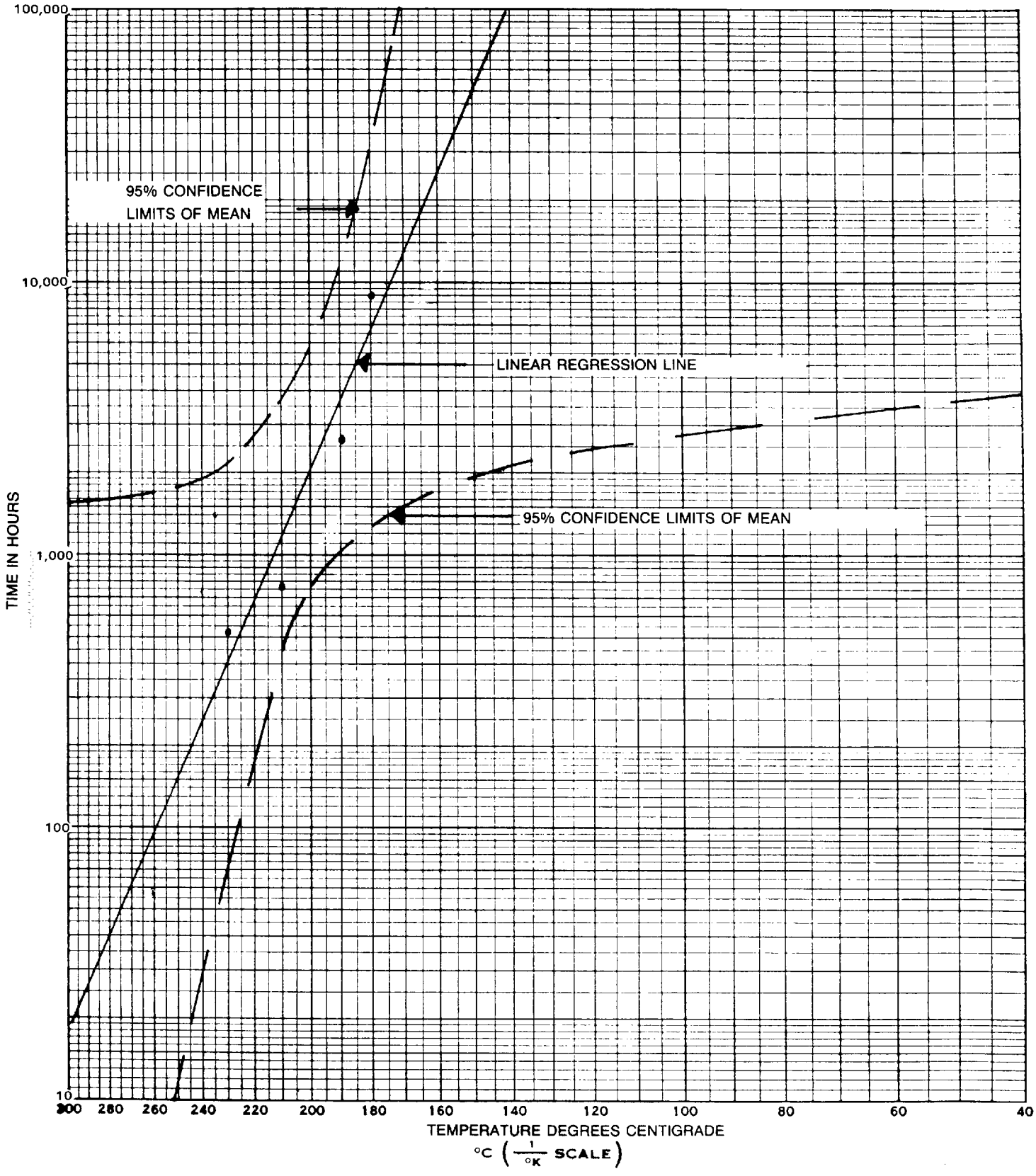


Figure A-24

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NEMA LI*6 93 ■ 6470247 0509697 0T8 ■

Grade G-3
Electric Strength
Arrhenius Curve at 50% of Original Strength
0.062 Inch (0.6 mm)
(See Note 2 on Page 6)

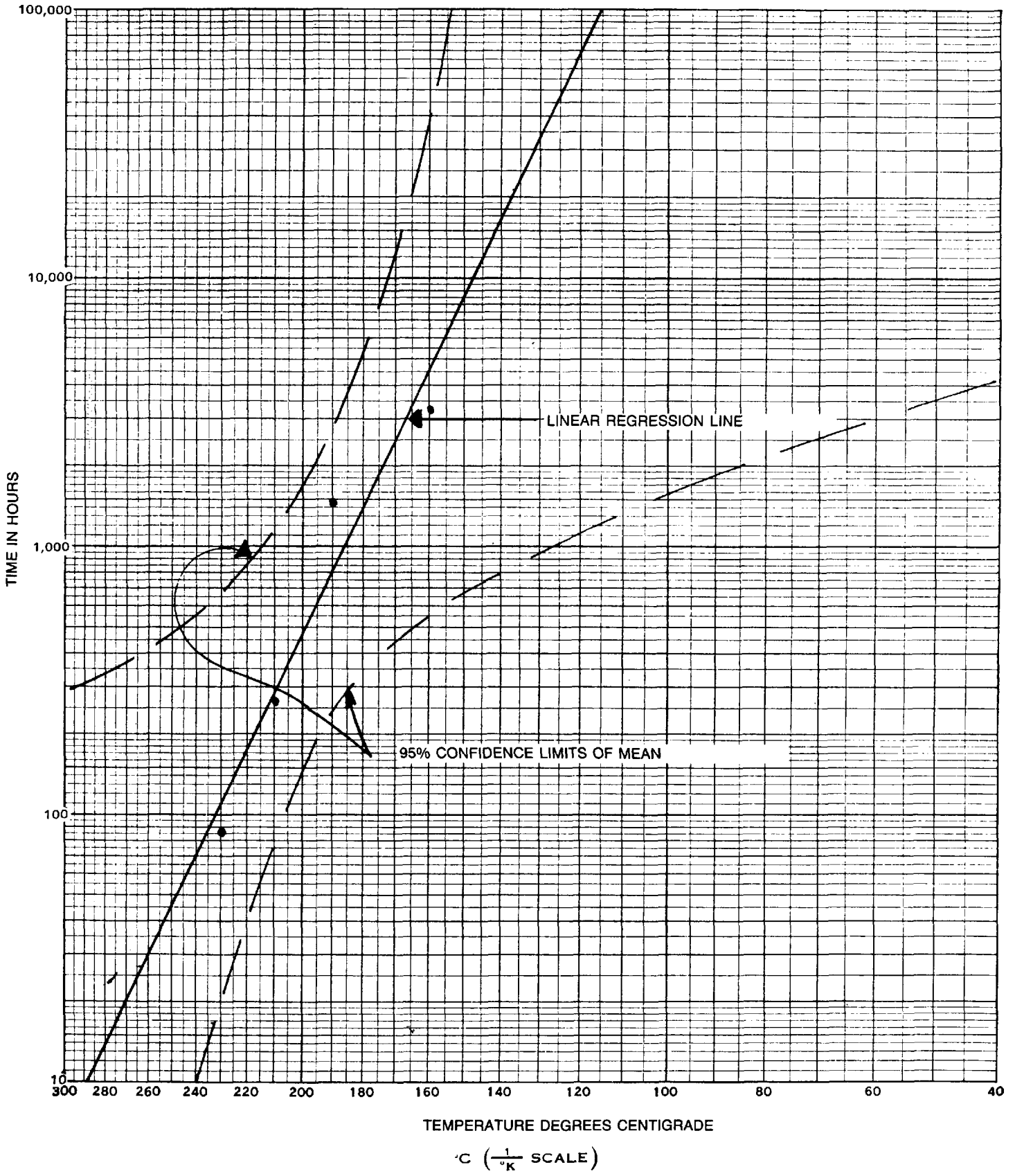


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Grade G-3
Electric Strength
Arrhenius Curve at 50% of Original Strength
0.031 Inch (0.8 mm)
(See Note 2 on Page)

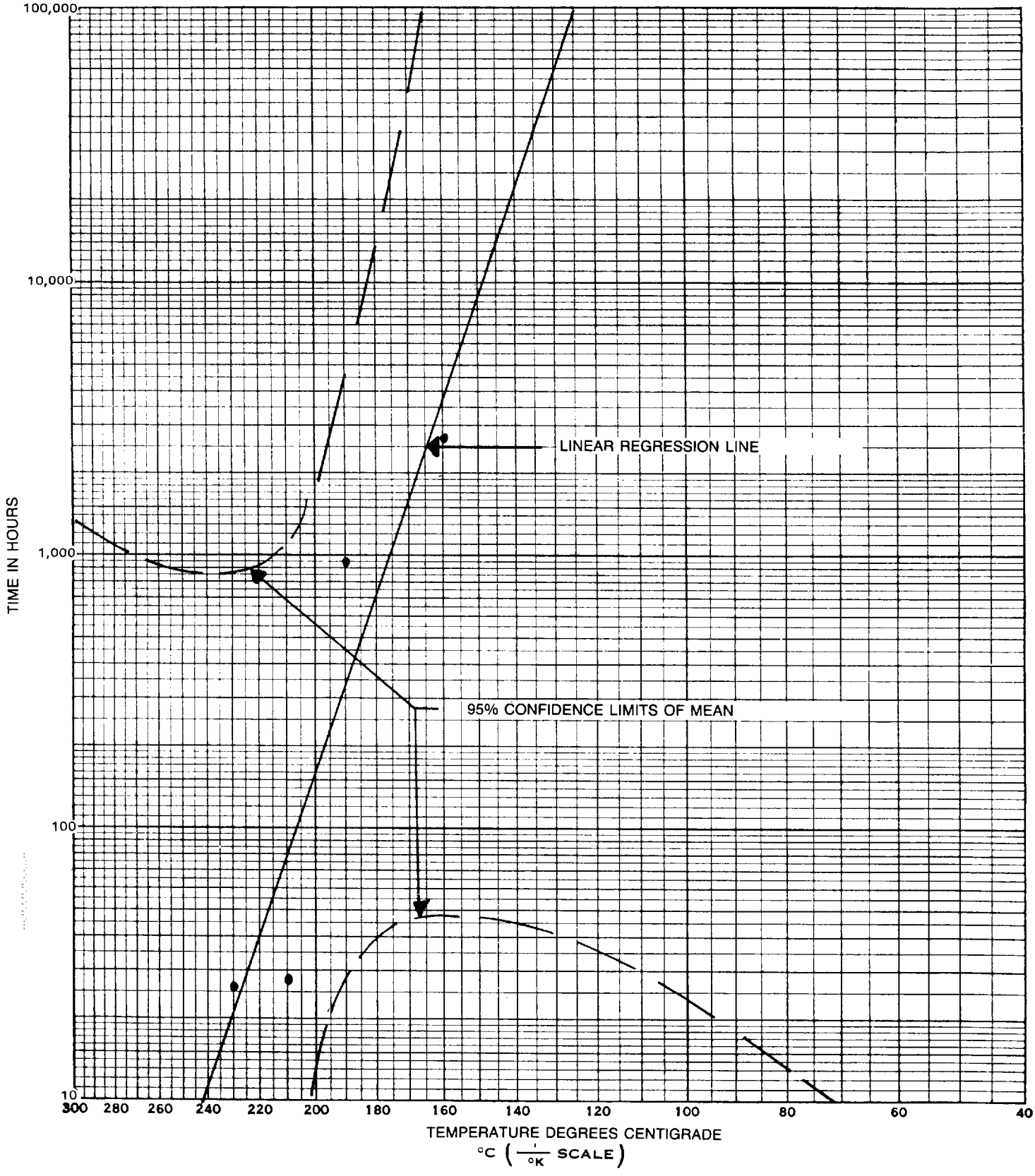


Figure A-26

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Grade F-7
Flexural Strength
Arrhenius Curve at 50% of Original Strength
0.062 Inch (0.6 mm)

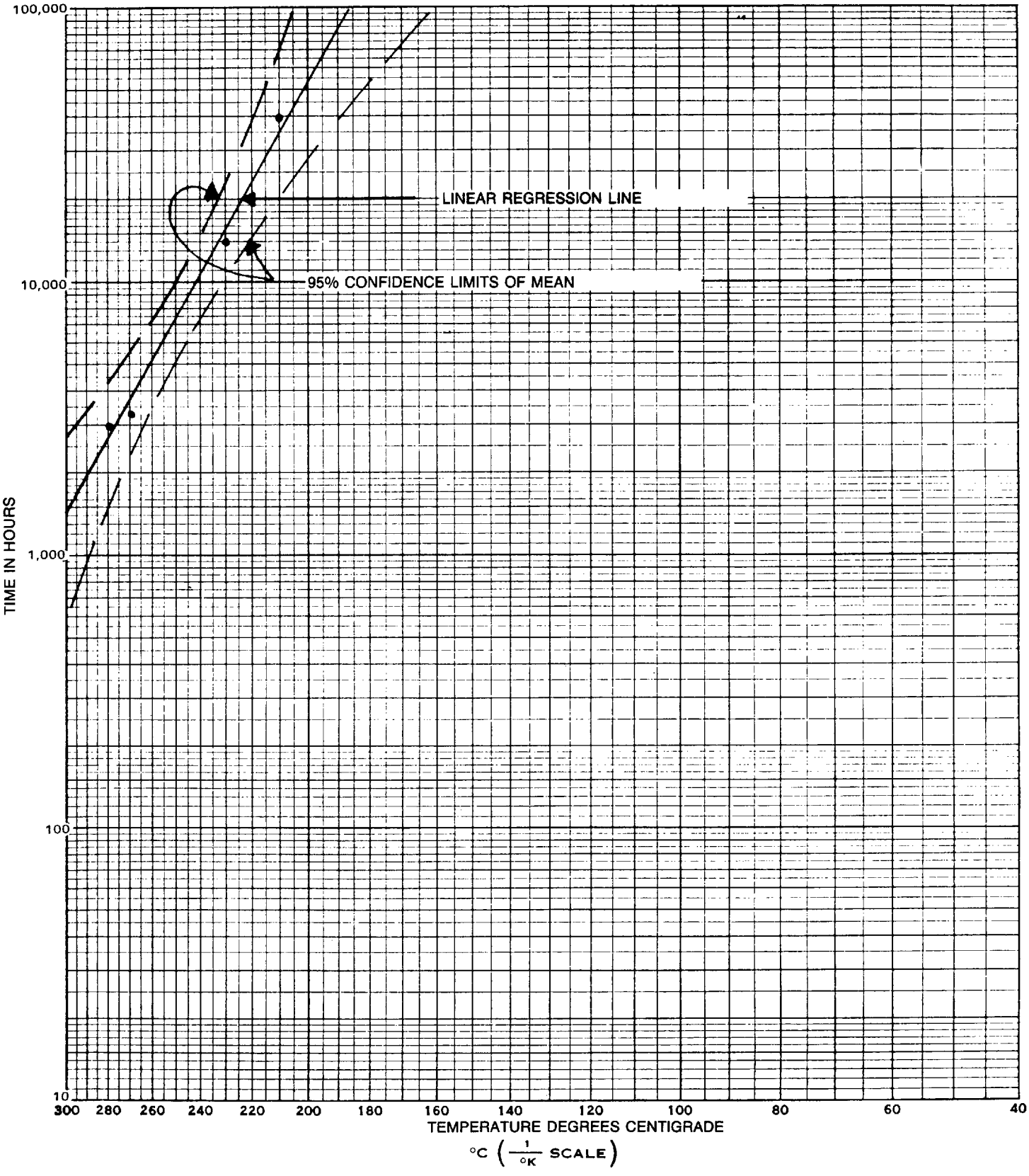


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Grade G-7
Flexural Strength
Arrhenius Curve at 50% of Original Strength
0.031 Inch (0.8 mm)

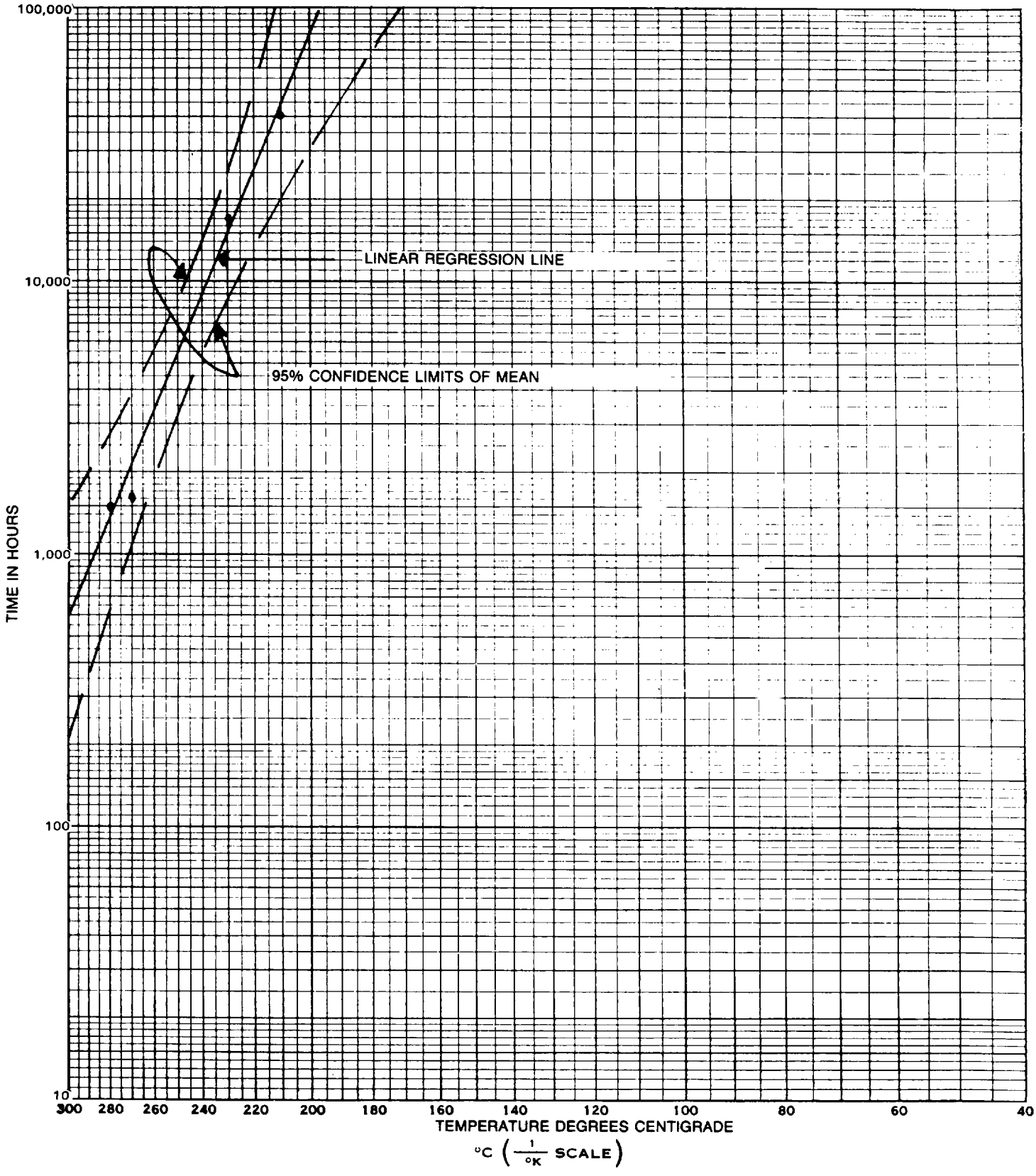


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Not for Resale

Grade G-7
Electric Strength
Arrhenius Curve at 50% of Original Strength
0.062 Inch (0.6 mm)
(See Note 2 on Page 6)

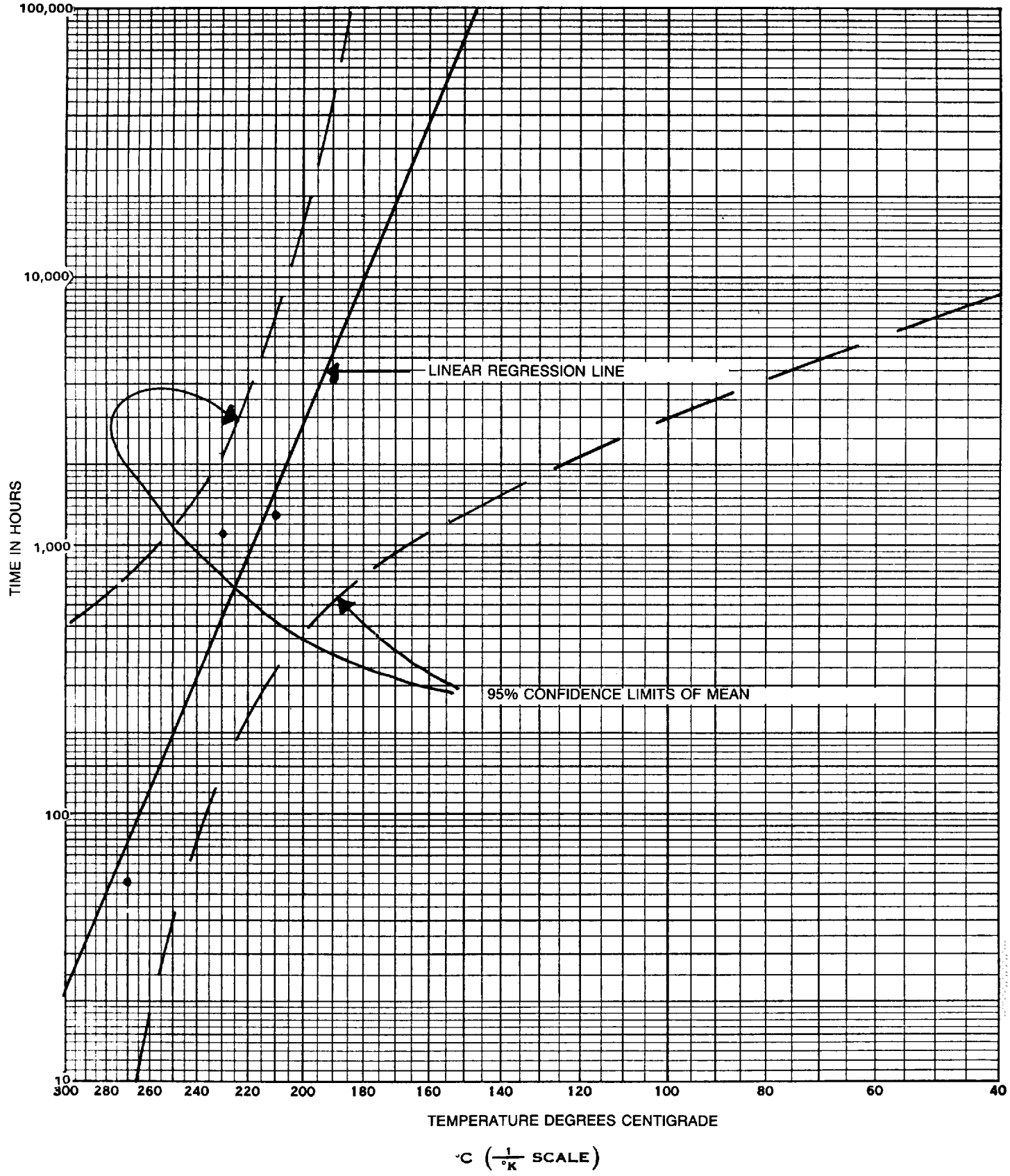


Figure A-29

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Grade G-7
Electric Strength
Arrhenius Curve at 50% of Original Strength
0.031 Inch (0.8 mm)
(See Note 2 on Page 6)

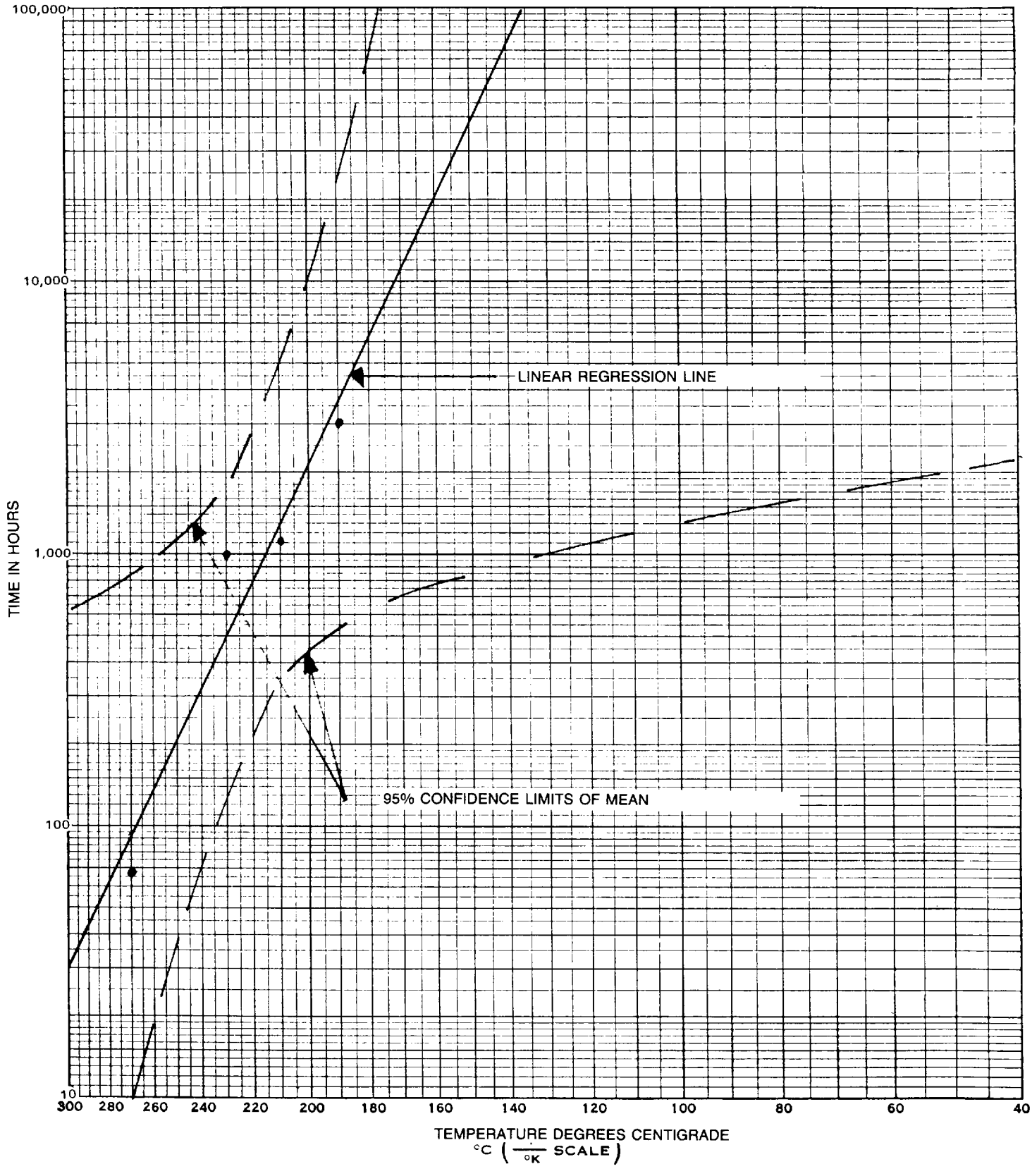


Figure A-30

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Grade G-9 and G-5
Flexural Strength
Arrhenius Curve at 50% of Original Strength
0.062 Inch (0.6 mm)

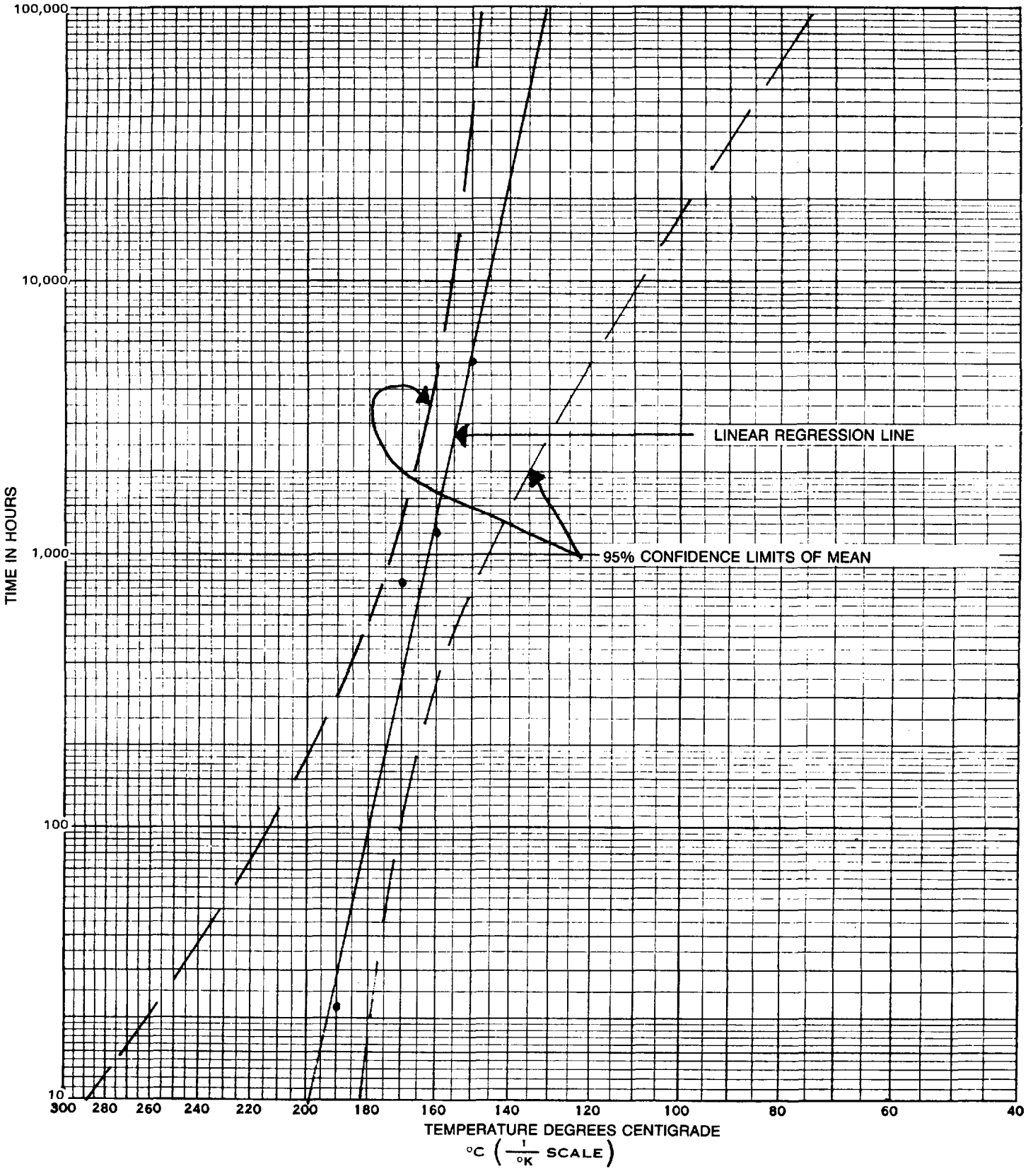


Figure A-31

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Grades G-9 and G-5
Flexural Strength
Arrhenius Curve at 50% of Original Strength
0.031 Inch (0.8 mm)

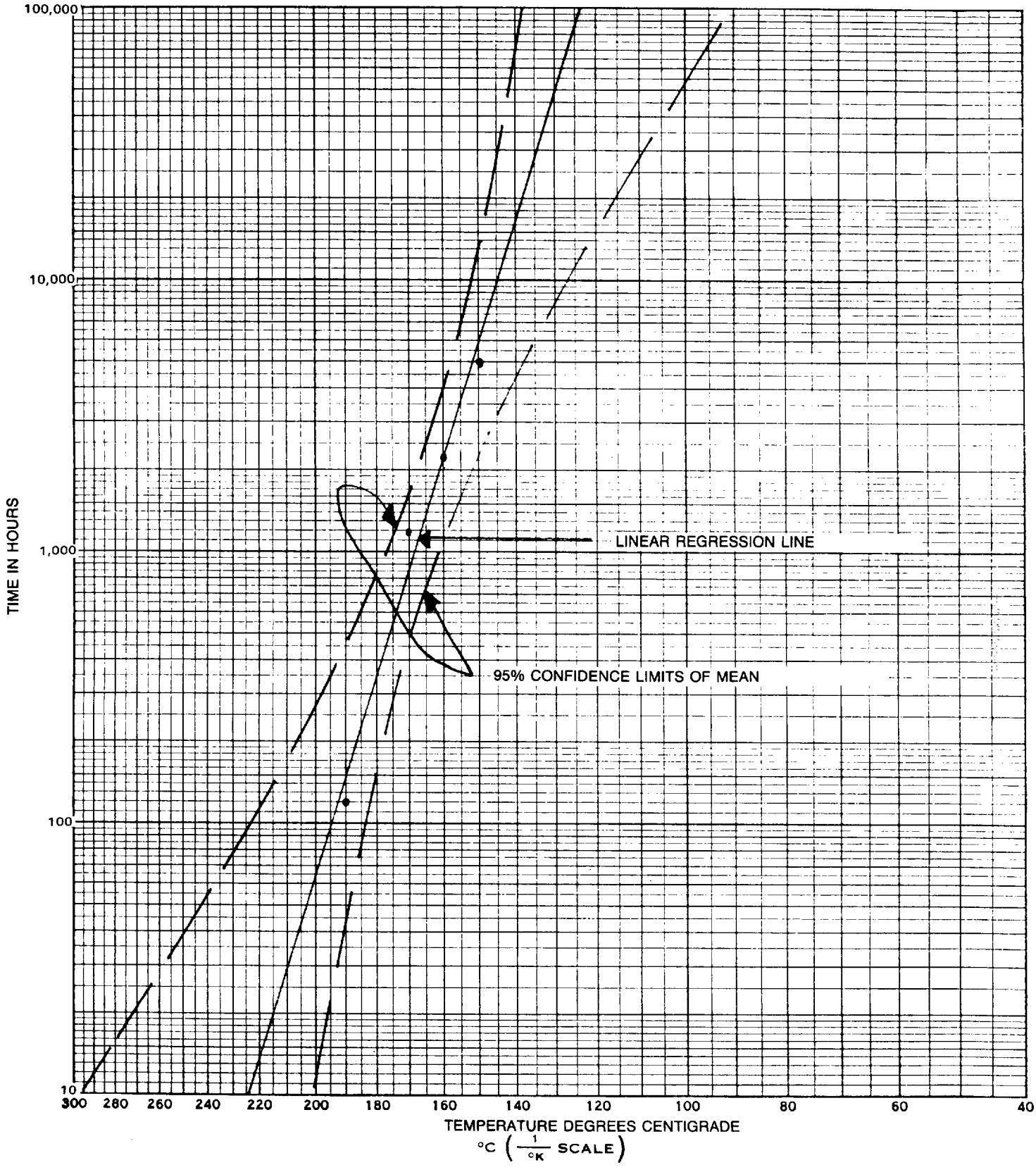


Figure A-32

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Grades G-9 and G-5
Electric Strength
Arrhenius Curve at 50% of Original Strength
0.062 Inch (0.6 mm)
(Not Recommended for Electrical Applications at Elevated Temperature)

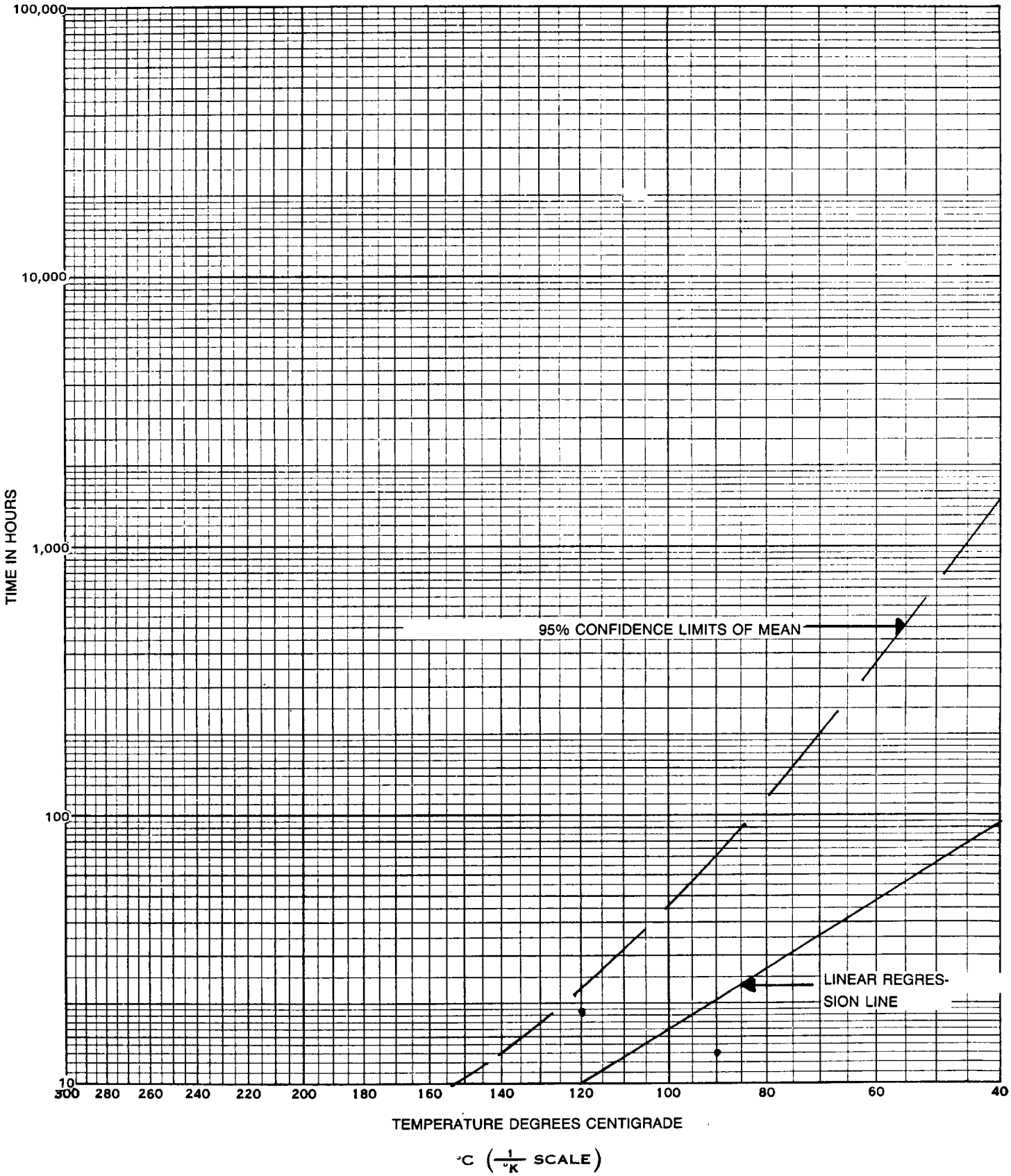


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Grades G-11 and FR-5
Flexural Strength
Arrhenius Curve at 50% of Original Strength
0.062 Inch (0.6 mm)

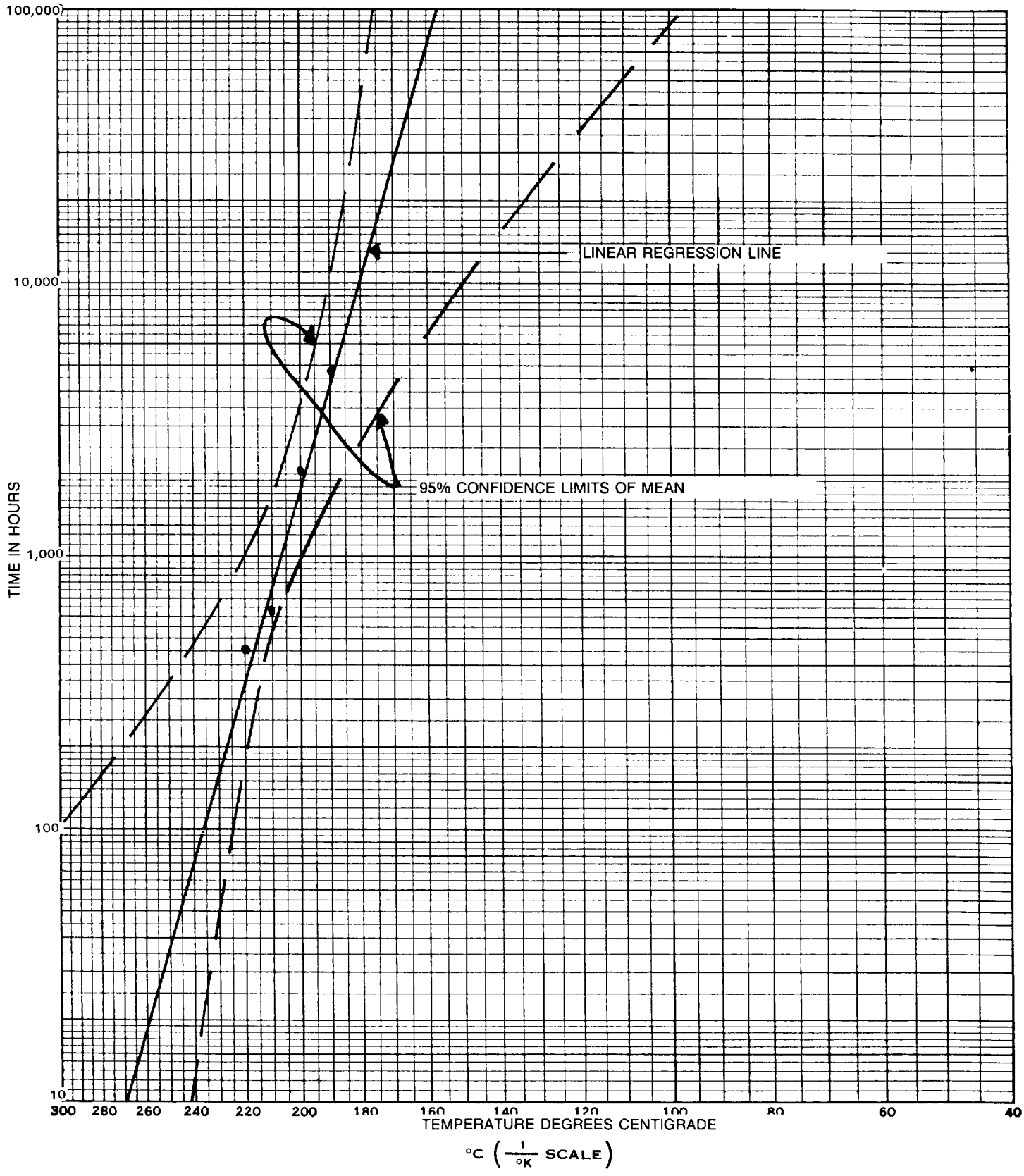


Figure A-34

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Grades G-11 and FR-5
Flexural Strength
Arrhenius Curve at 50% of Original Strength
0.031 Inch (0.8 mm)

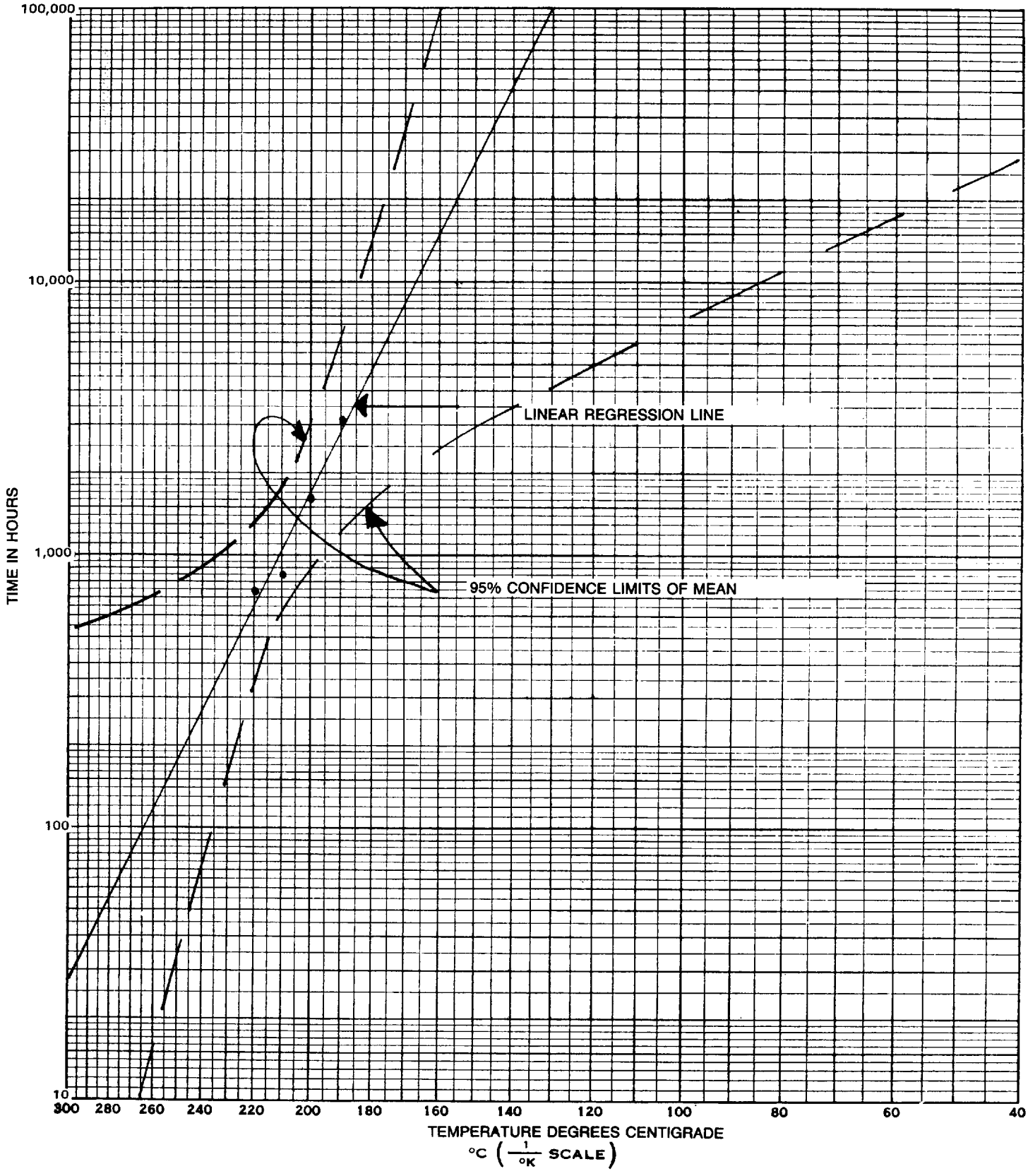


Figure A-35

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Not for Resale

Grades G-11 and FR-5
Electric Strength
Arrhenius Curve at 50% of Original Strength
0.062 Inch (0.6 mm)

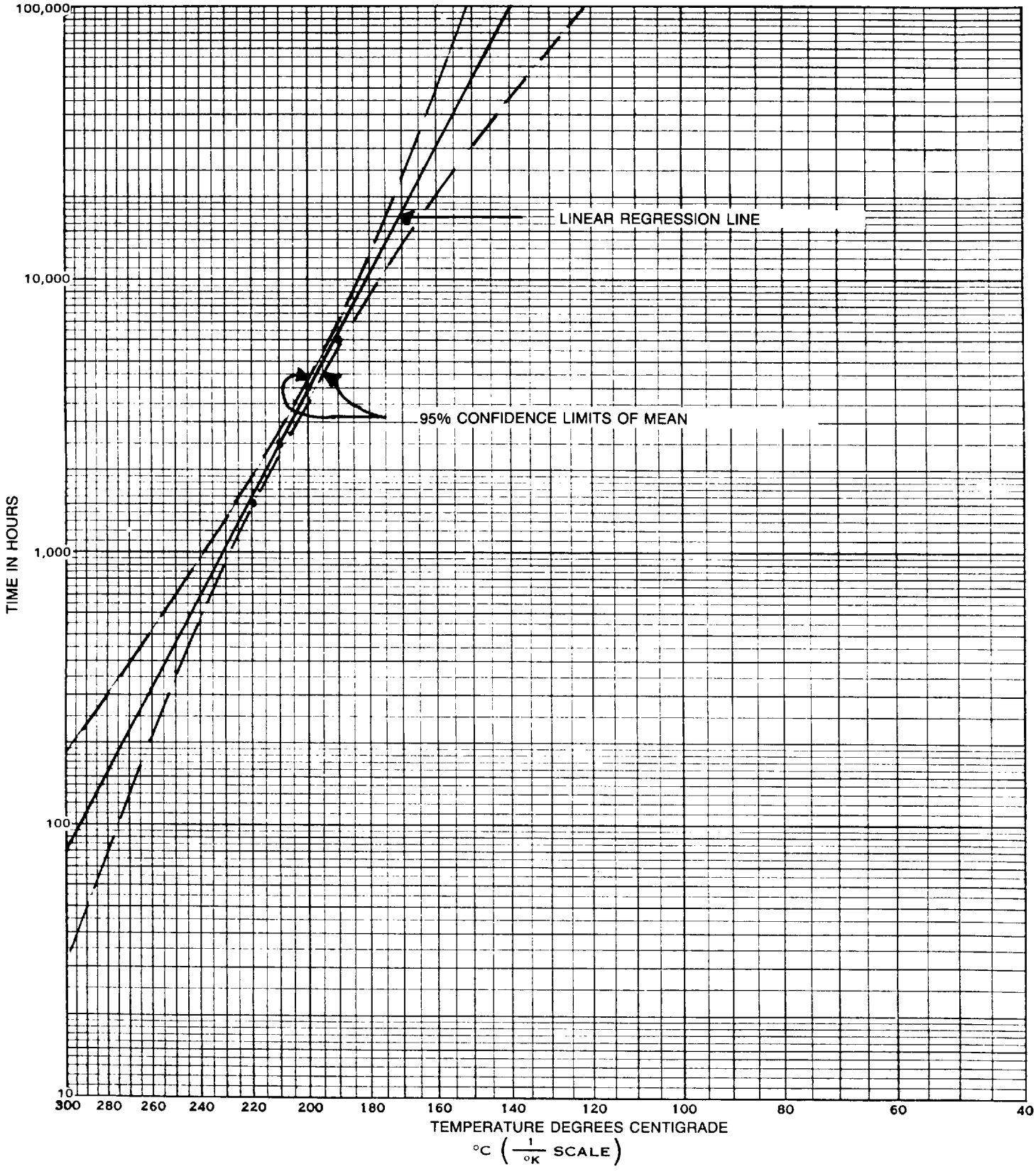


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Not for Resale

Grades G-11 and FR-5
Electric Strength
Arrhenius Curve at 50% of Original Strength
0.031 Inch (0.8 mm)

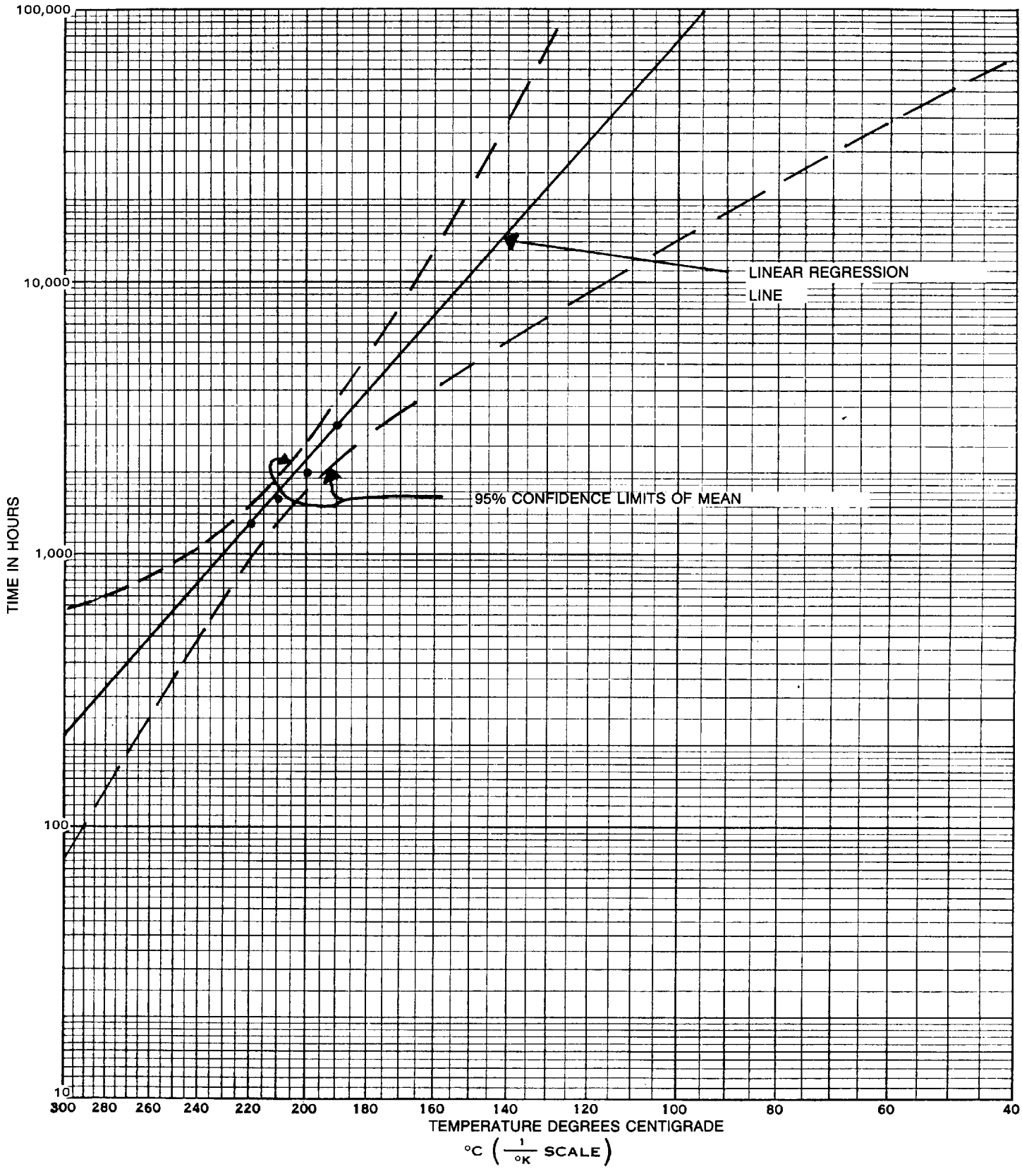


Figure A-37

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Grade GPO-2
Flexural Strength
Arrhenius Curve at 50% of Original Strength
0.062 Inch (0.6 mm)

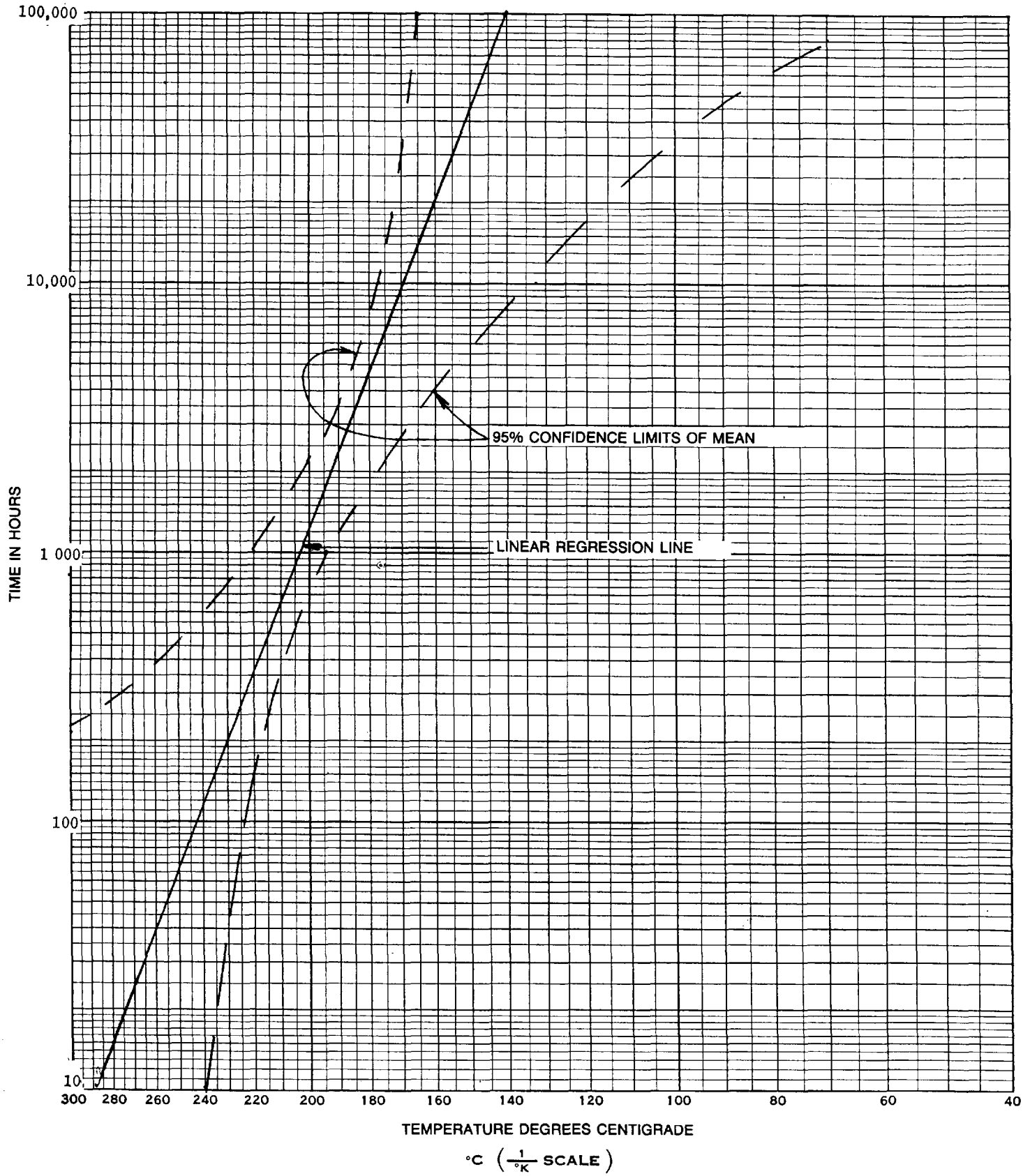


Figure A-38

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Grade GPO-2
Electric Strength Perpendicular to Lamination
Arrhenius Curve at 50% of Original Strength
0.062 Inch (0.6 mm)

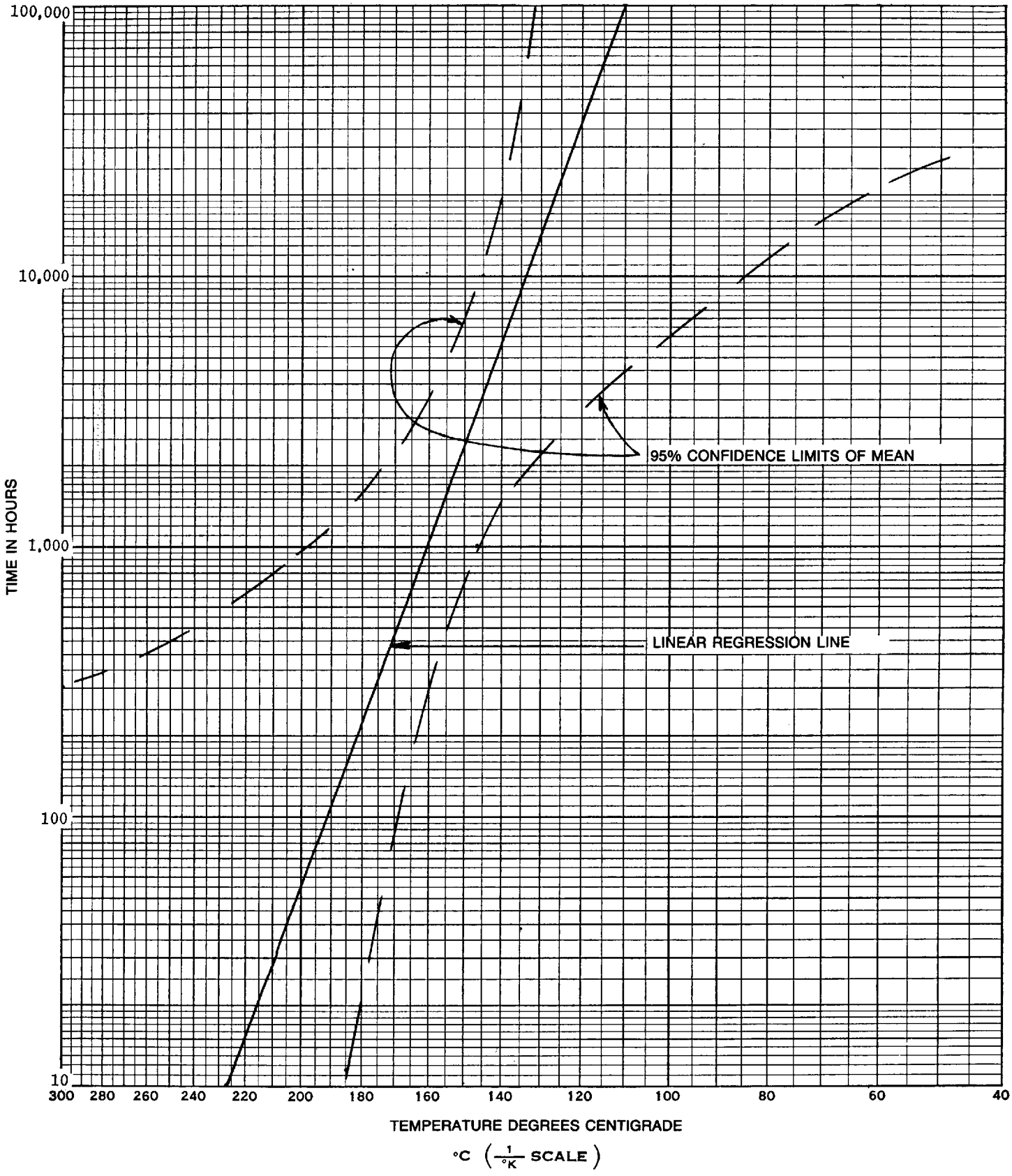


Figure A-39

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Grade GPO-3
Flexural Strength
Arrhenius Curve at 50% of Original Strength
0.062 Inch (0.6 mm)

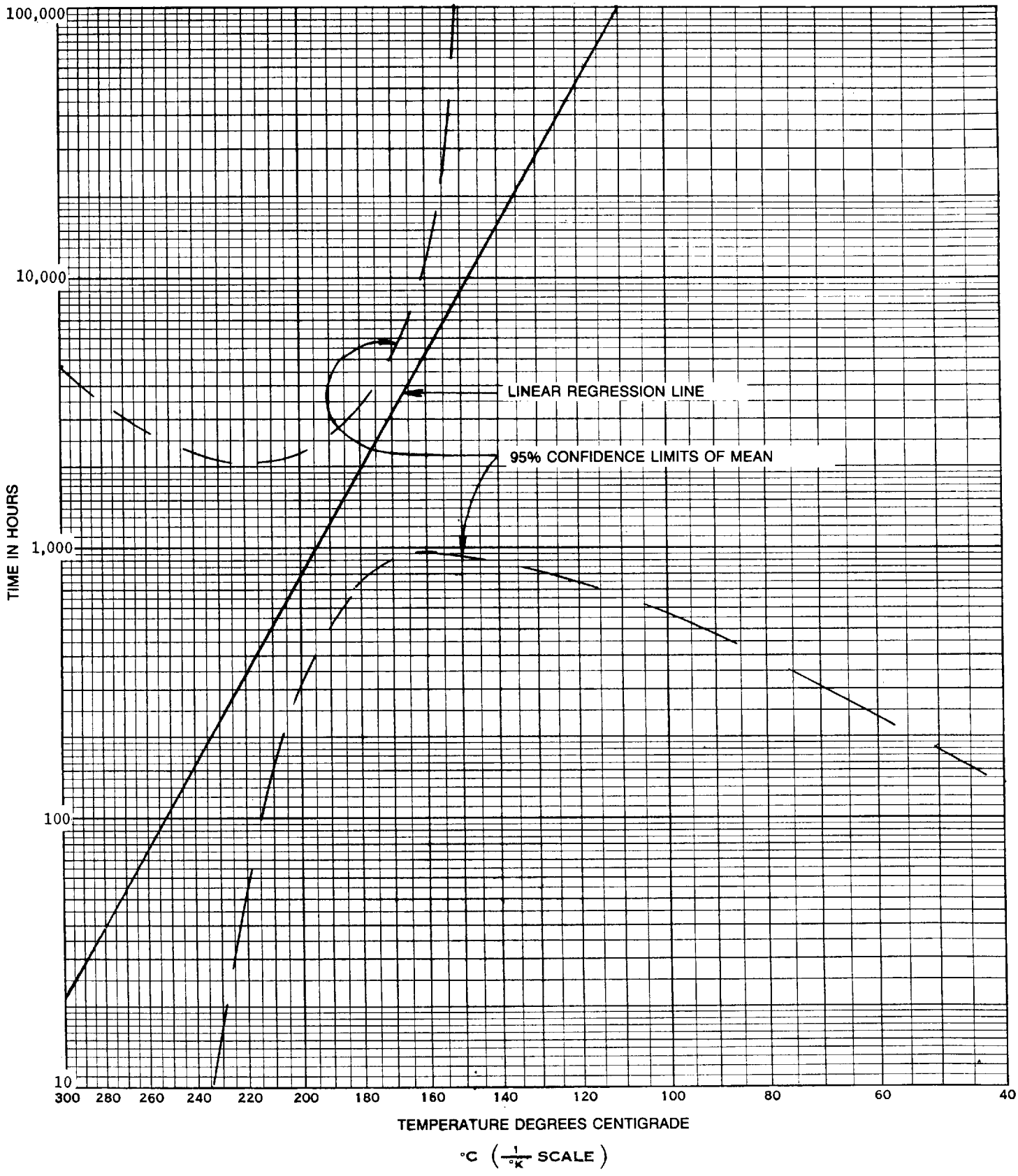


Figure A-40

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Grade GPO-3
Electric Strength Perpendicular to Lamination
Arrhenius Curve at 50% of Original Strength
0.062 Inch (0.6 mm)

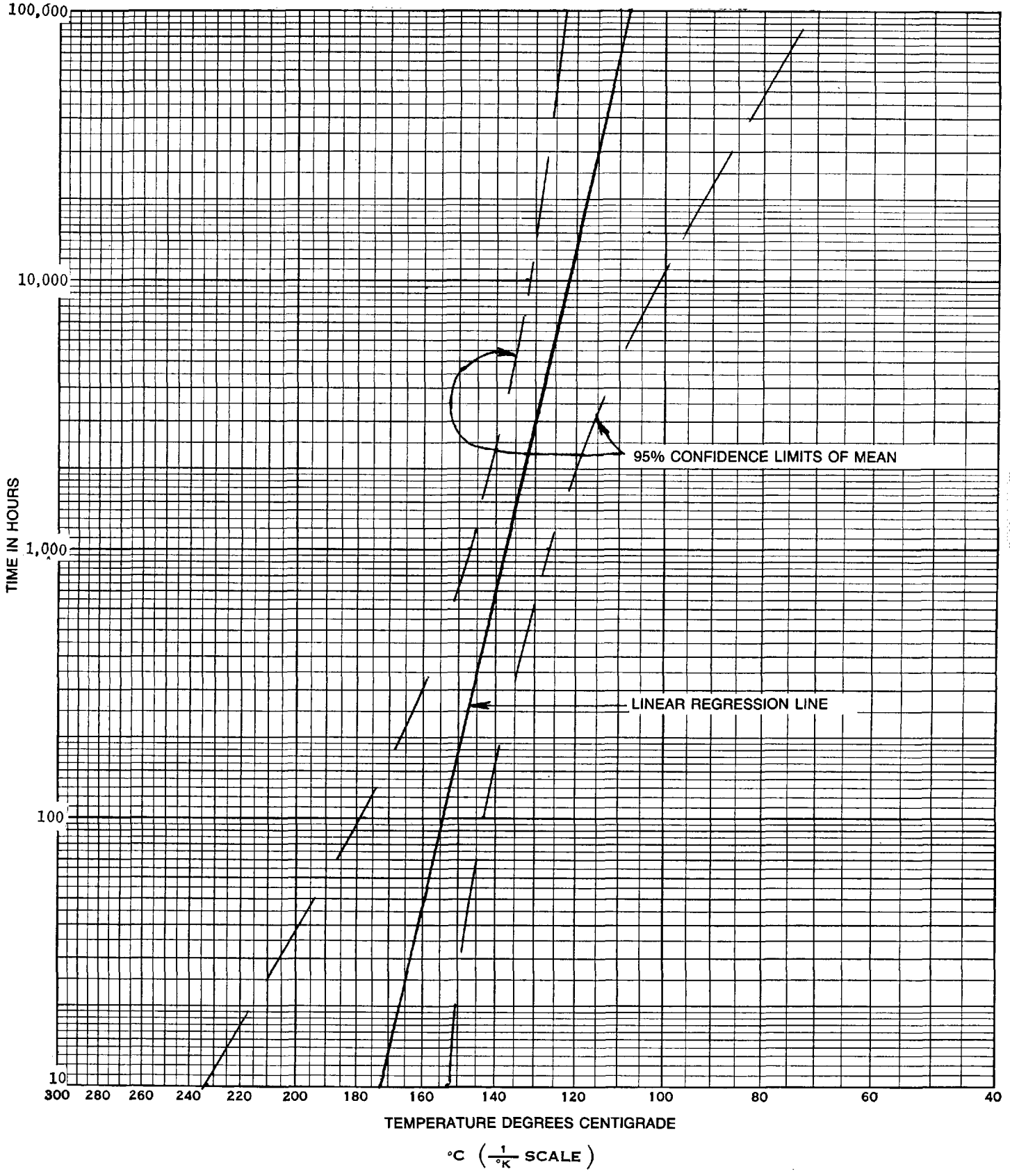


Figure A-41

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Grade CEM-1
Flexural Strength
Arrhenius Curve at 50% of Original Strength
0.062 Inch (1.6 mm)

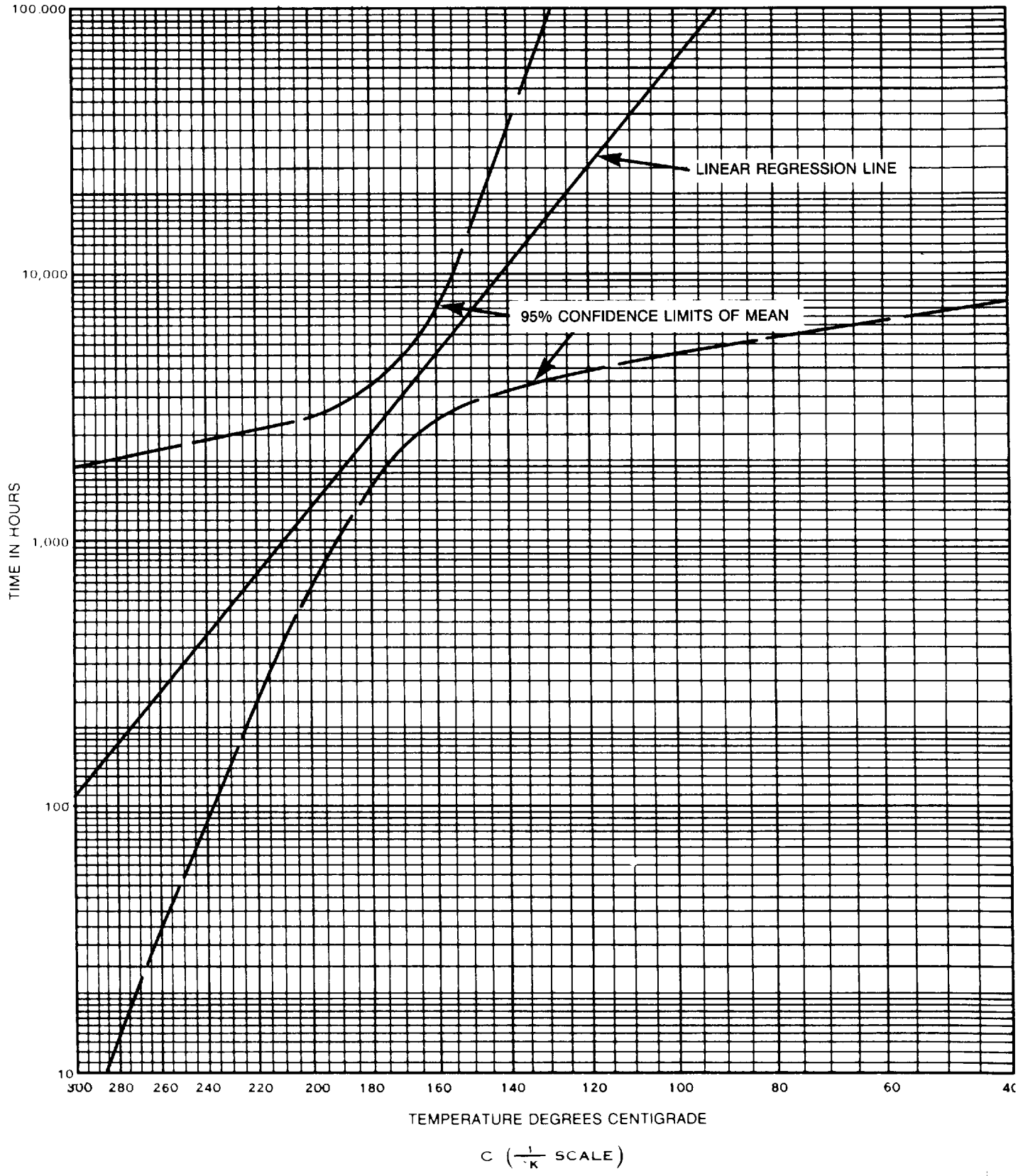


Figure A-42

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Grade CEM-1
Flexural Strength
Arrhenius Curve at 50% of Original Strength
0.031 Inch (0.8 mm)

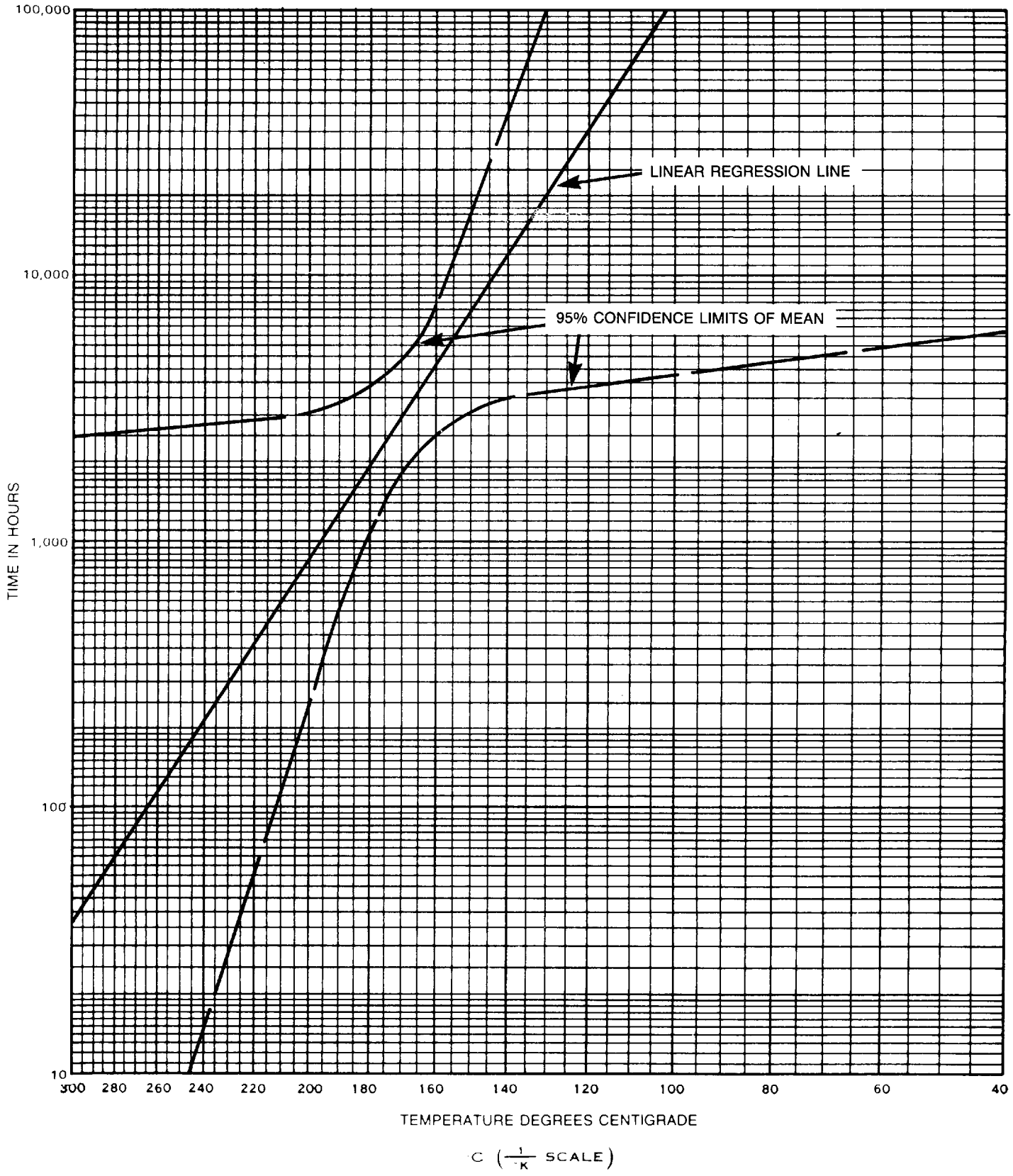


Figure A-43

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Grades CEM-1 and CEM-3
Electric Strength
Arrhenius Curve at 50% of Original Strength
0.062 Inch (1.6 mm)

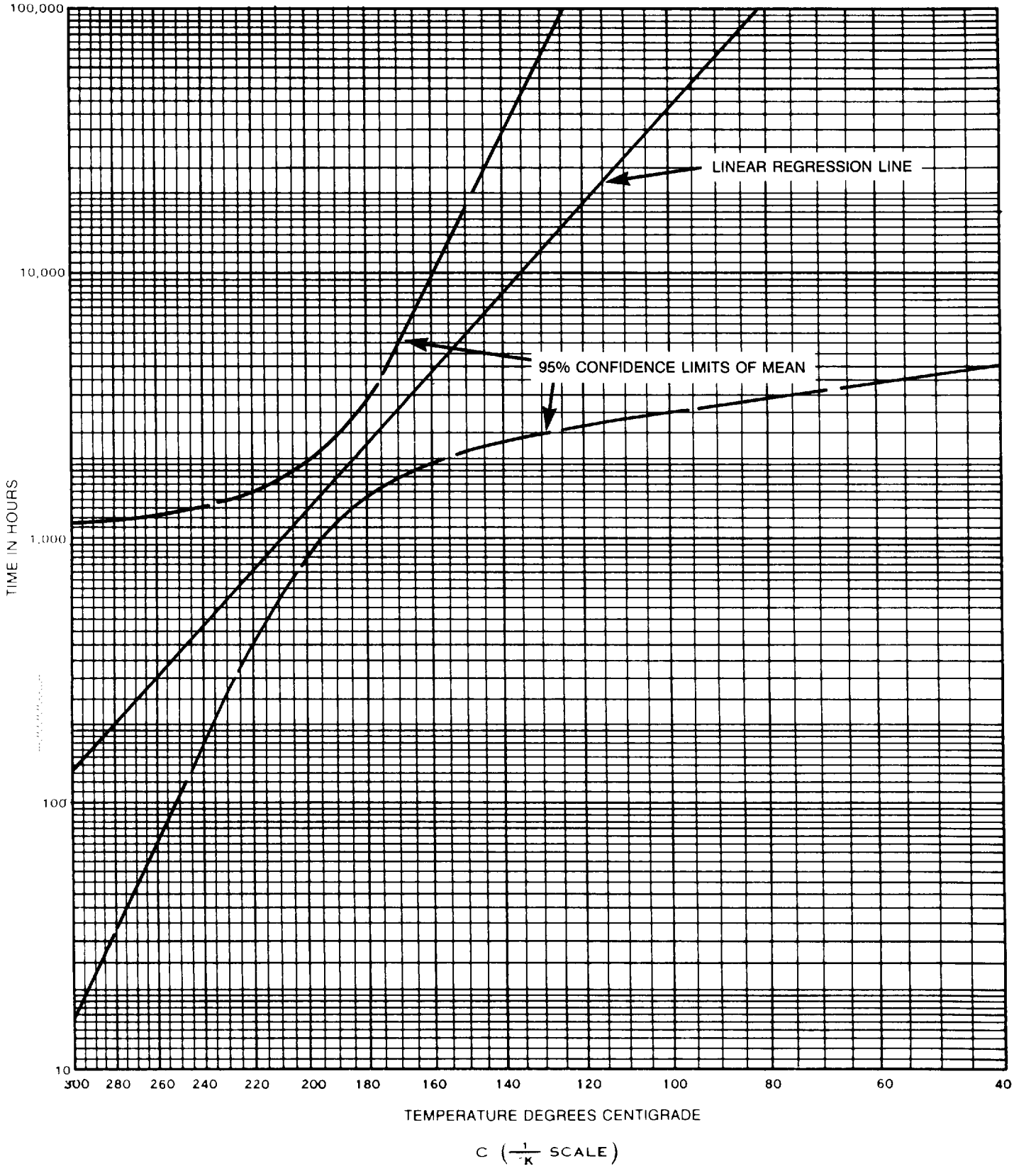


Figure A-44

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Grades CEM-1 and CEM-3
Electric Strength
Arrhenius Curve at 50% of Original Strength
0.031 Inch (0.8 mm)

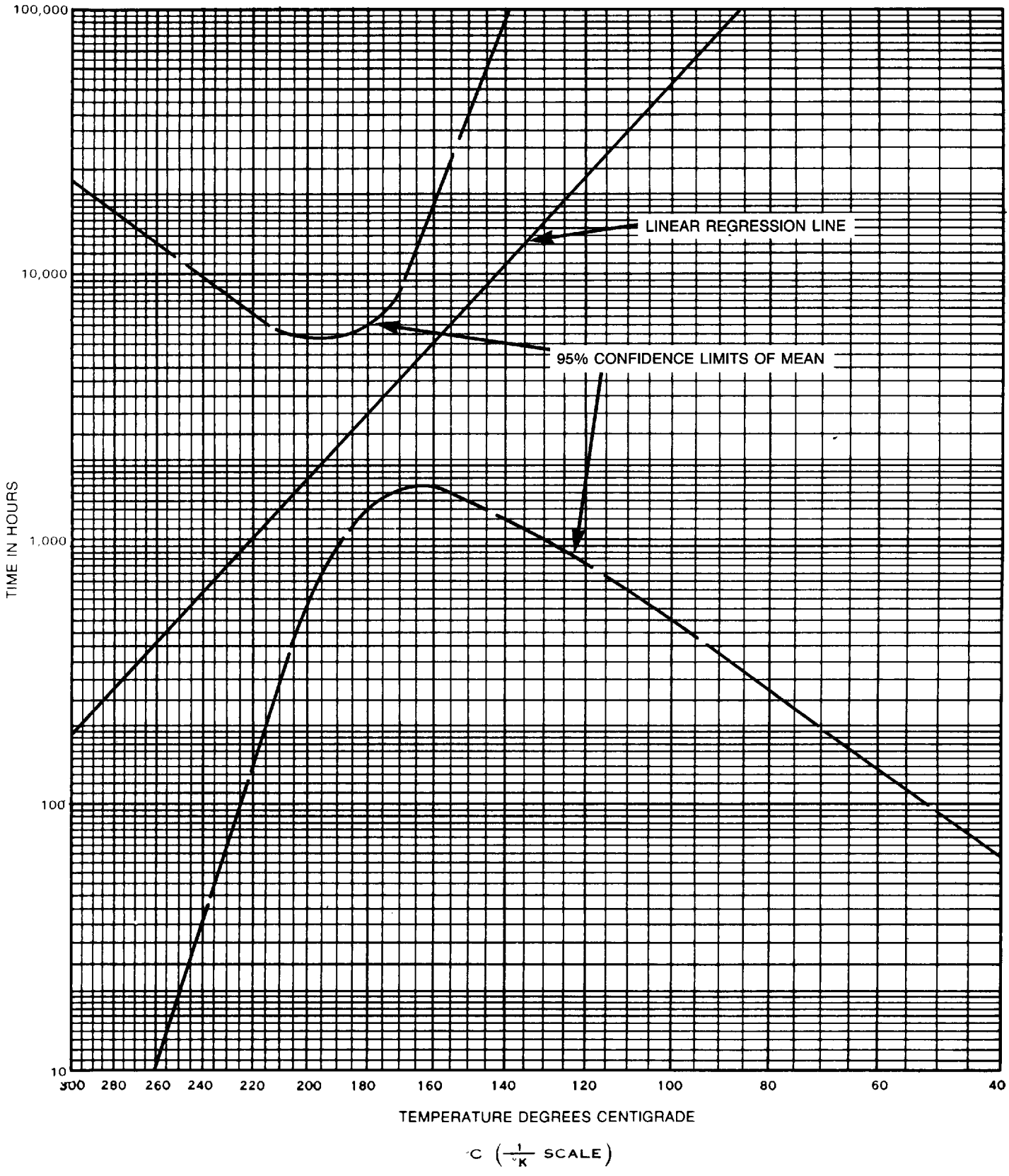


Figure A-45

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Grade CEM-3
Flexural Strength
Arrhenius Curve at 50% of Original Strength
0.062 Inch (1.6 mm)

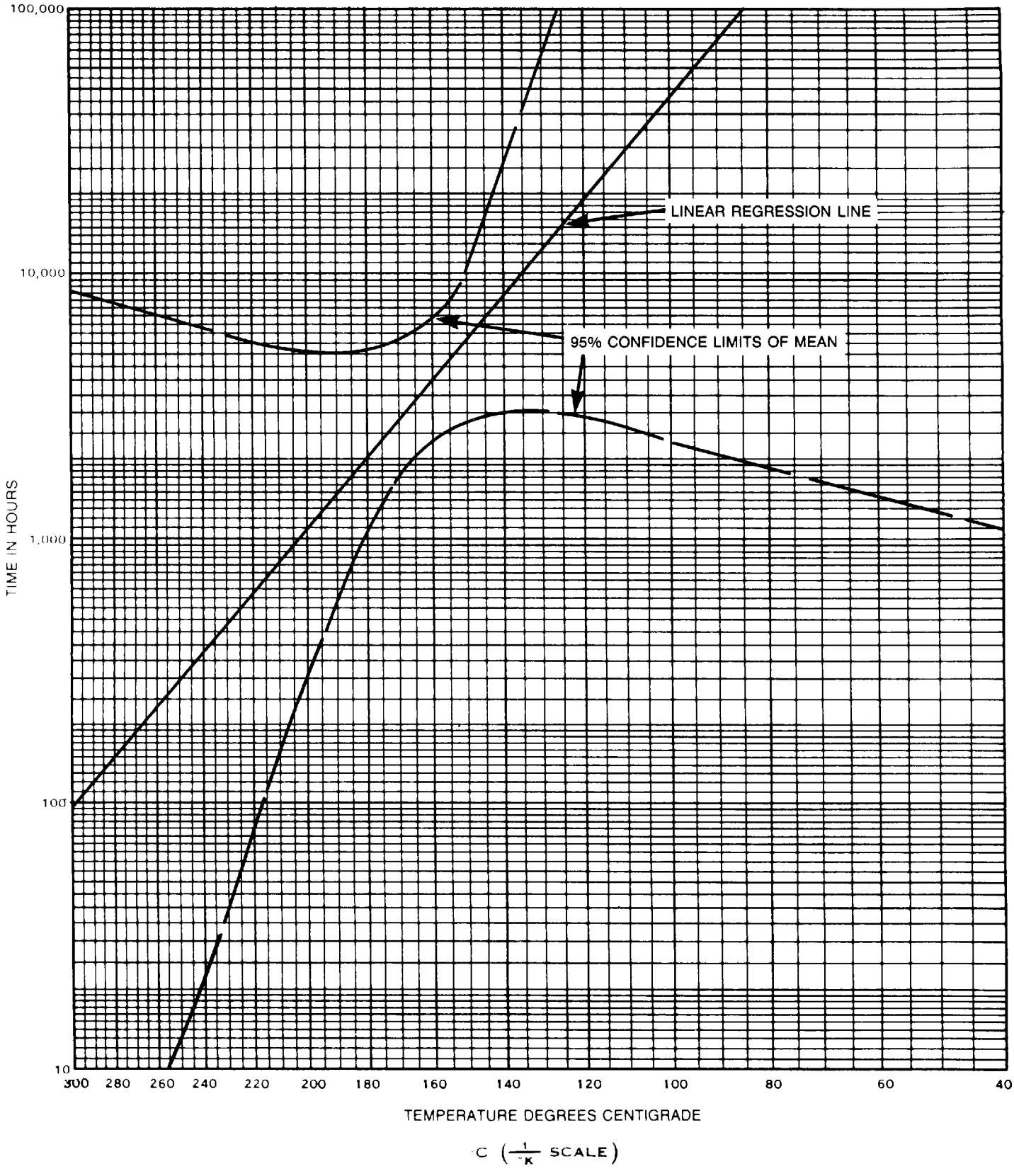


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Grade CEM-3
Flexural Strength
Arrhenius Curve at 50% of Original Strength
0.031 Inch (0.8 mm)

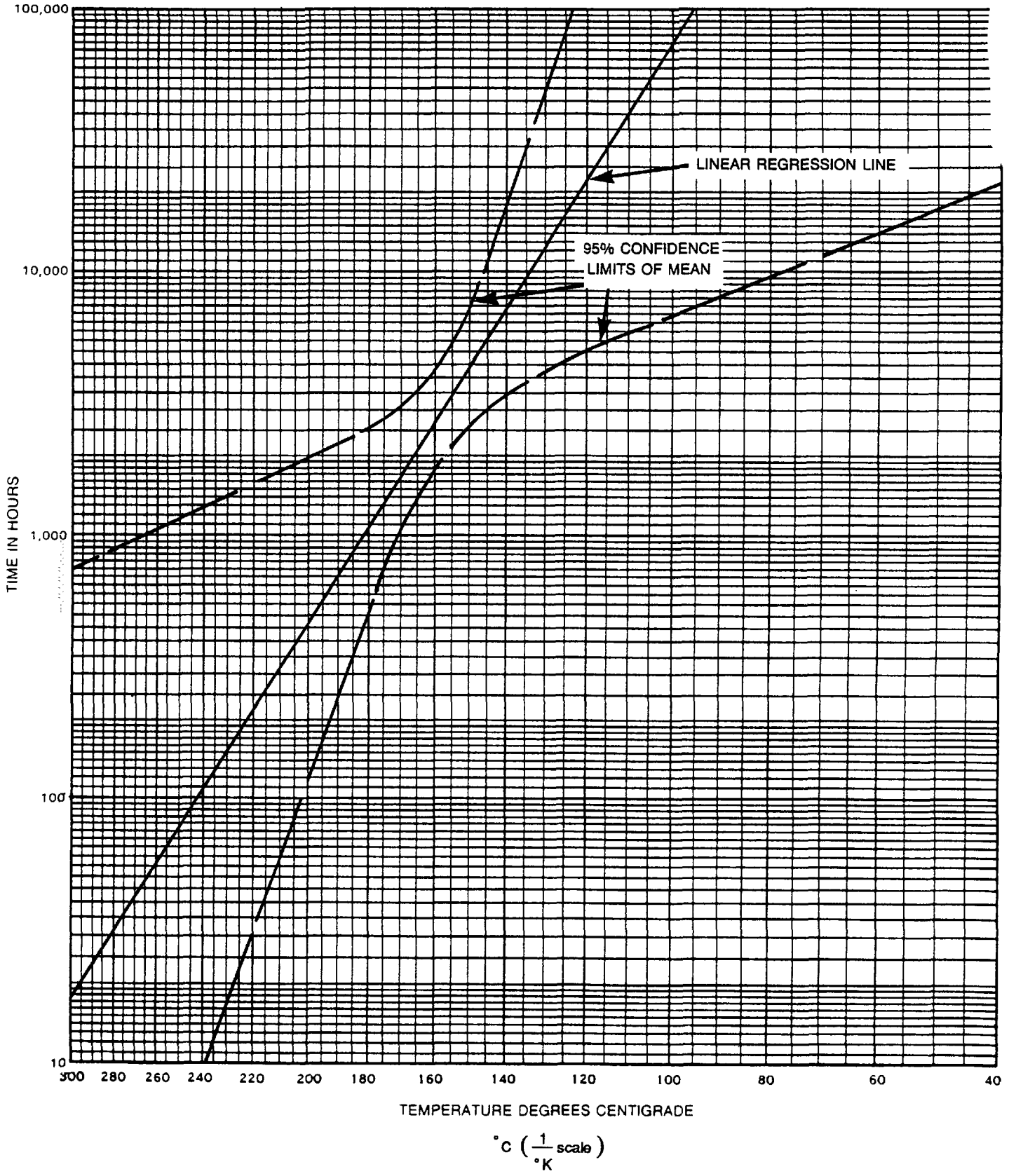


Figure A-47

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NEMA STANDARDIZATION BACKGROUND

The purpose of NEMA standards, their classification, and status are set forth in certain clauses of the NEMA *Standardization Policies and Procedures* manual and are referenced below:

Purpose of Standards

National Electrical Manufacturers Association Standards are adopted in the public interest and are designed to eliminate misunderstandings between the manufacturer and the purchaser and to assist the purchaser in selecting and obtaining the proper product for their particular needs. Existence of a National Electrical Manufacturers Association Standard does not in any respect preclude any member or nonmember from manufacturing or selling products not conforming to the standard.

Definition of a Standard

A standard of the National Electrical Manufacturers Association defines a product, process, or procedure with reference to one or more of the following: nomenclature, composition, dimensions, tolerances, safety, operating characteristics, performance, rating, testing, and the service for which they are designed.

(Standardization Policies and Procedures, p. 1)

Dimensions

Where dimensions are given for interchangeability purposes, alternate dimensions satisfying the other provisions of the Standards Publication may be capable of otherwise equivalent performance.

(Standardization Policies and Procedures, p. 6)

Categories of Standards

National Electrical Manufacturers Association Standards are of three classes, which have received the affirmative vote of at least two-thirds of the Subdivision votes cast in the affirmative or negative:

1. NEMA Standard, which relates to a product, process, or procedure commercially standardized and subject to repetitive manufacture.
2. Suggested Standard for Future Design, which may not have been regularly applied to a commercial product, but which suggests a sound engineering approach to future development.
3. Adoptive Standard, which is adopted in whole or in part from the standards of another organization, either domestic, regional, or international.

(Standardization Policies and Procedures, pp. 5)

Authorized Engineering Information

Authorized Engineering Information consists of explanatory data and other engineering information of an informative character not falling within the classification of NEMA Standard or Suggested Standard for Future Design, which standard has received the affirmative vote of at least two-thirds of the Subdivision votes cast in the affirmative or negative.

(Standardization Policies and Procedures, pp. 5)

Identification of Status

Standards in NEMA Standards Publications are identified as "NEMA Standard," "Suggested Standard for Future Design," or "Adoptive Standard." These indicate the status of the standard. A statement incorporating the auxiliary verb "shall" indicates that compliance with a requirement is mandatory for compliance with the standard. These classes of standards are identified in the foreword or throughout the text.

The material identified as "Authorized Engineering Information" is designated similarly. Statements incorporating other auxiliary verbs such as "should," "may," etc. refer to the authorized engineering information and not to procedures required for compliance with the standard.

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AlliedSignal Laminate Systems
La Crosse, WI 54602-1448

Current, Inc.
East Haven, CT 06512

GE Electromaterials
Coshocton, OH 43812

Glastic Corporation
Cleveland, OH 44121

Haysite Reinforced Plastics Company
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Noblesville, IN 46060

Iten Industries
Ashtabula, OH 44004

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