THE UNIVERSITY OF MICHIGAN
COLLEGE OF ENGINEERING
Department of Chemical and Metallurgical Engineering

Progress Report No. 1

EVALUATION OF STRONTIUM-BEARING POST-INOCULANTS (SUPERSEED)

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SUMMARY

The objective of this investigation is to evaluate the use of two types of strontium-bearing ferrosilicon (Superseed 1 and 2) as ladle post-inoculants for nodular iron.

This report summarizes the progress which has been made in the first four months of the investigation, directed toward the following points.

Comparison of Superseed with 75% Si ferrosilicon as a post-inoculant when equal amounts of silicon are added (.5%) in each case. Three types of magnesium inoculant (MgFeSi) (CeMgFeSi) and (NiMg) were used. Chill wedges and Y-blocks from 1/4 to 3 in. thick were poured under controlled conditions.

The ranges of mechanical properties and nodule characteristics over this range of sections may be summarized as follows:

Post-inoculant	Magnesium Inoculant	Nodularity %	Nodules per in^{2}x 10^{-3}	Tensile psi/1000	Elongation %	Heat Ref
Superseed No. 1	MgFeSi	55-89	66-34	55-56	11-8	7
75% FeSi	"	97-64	211-49	63-70	27-3	5
Superseed No. 1	CeMgFeSi	97-75	150-31	61-67	27-15	8
75% FeSi	"	99-87	276-36	60-66	28-20	4
Superseed No. 1	NiMg	96-89	140-52	68-82	21-11	9
75% FeSi	"	97-84	137-35	84-107	14-3	6

The most important conclusion about these heats from an engineering standpoint is that Superseed No. 1 produces satisfactory values of elongation in the 3-in. Y-block. By contrast, unsatisfactory elongation (3%) is obtained with 75% ferrosilicon in two out of three comparable test castings. Also, in the case where the inoculant was MgFeSi, the nodularity fell to 64% in the 3-in. Y-block. The use of Ce-bearing inoculant with Superseed No. 1 was accompanied by somewhat lower elongation in the 3-in. Y-block but the value (15%) was still satisfactory.

The experiments will be continued to check reproducibility of data at other residual magnesium levels and to evaluate Superseed No. 2. It is recommended that future work be directed toward the determination of minimum levels

of Superseed addition. Also, the better performance of Superseed in heavy sections indicates that it may exhibit a greater resistance to "fading."

INTRODUCTION

The use of strontium-containing ferrosilicon (Superseed) as an inoculant for gray iron has been very satisfactory. A natural development is an extension of this use as a post-inoculant for ductile iron. Preliminary reports from the field indicated that there might be an unfavorable interaction when cerium-bearing magnesium alloys were used. Other considerations to be investigated before releasing Superseed for general use are: Optimum amounts of addition; Fading effect; Effectiveness with different magnesium inoculants; Section sensitivity; Chill reduction; Basic solidification characteristics; Nodularity and nodule count as functions of section; Effects with different nodular iron composition such as high-manganese, pearlitic austenitic irons, etc.; Comparison with SMZ.

As a start, it was agreed in conference with the New Products Section to compare Superseed with 75% ferrosilicon using the same amount of added silicon. A small but representative group of test castings was selected to determine the effects of section size upon mechanical properties and nodule structure. To minimize the effect of time after inoculation (fading effect) the objective was to pour all castings in less than two minutes. After a few practice heats it was found possible to hold this time to less than one minute, as described in the following section.

EXPERIMENTAL PROCEDURE

MOLDING

The molds poured and their descriptions are listed below in the order in which they were poured.

Description	Mold Material	Remarks
Wedge	Core Sand	Triangular-base 1/2" x height 1 1/2"
Chill Wafer	Core Sand	6" x 3" x 3/4"
1/4" Y-Block	Dry Sand	Y-Block, all castings in one flask
1/2" Y-Block		
1" Y-Block		
3" Y-Block		
Castability Bar	Dry Sand	2" x 2" x 12"
Wedge	Core Sand	See above
Chill Wafer	Core Sand	

The chill wafer is poured against a graphite plate while the wedge chills at the acute angle of the triangular cross-section. The sand used for the Y-blocks and the castability bar has the following composition: 4% Western bentonite, 0.3% Dextrin; 0.7% Woodflour; 3.5% Water. After the molds have been made on a jolt-squeeze machine, they are dried in an oven at 300°F for 12 hours.

The castability bar has a graphite chill at one end and a 4" dia. x 4" high riser at the other. Thermocouples are placed at 1", 3", 5", 7", 9", and 11" from the chill. Twenty-eight gauge chromed-alumel thermocuples are inserted in 1-mm-bore fused silica tubes. Temperature readings are then taken at six stations as a function of time.

MELTING

The raw materials charged to the 3000 cycle induction furnace are: Sorel pigiron, Armco iron, standard high carbon 70% FeMn, and high purity silicon metal. The FeMn and silicon metal are placed at the bottom of the furnace and as much pig iron as possible is added. The Armco iron is used to fill the voids. Upon initiation of melting the remainder of the pig iron is added.

When the metal is completely molten, 2 lbs of CaC_2 (nut size) is added as a protective cover for the melt. The power is then turned off and the carbide cover is removed when the melt reaches 2900°F. Upon cooling to 2750°F, the metal is treated with the magnesium alloy by the transfer technique in an open ladle. The post-inoculant is added to the furnace and the metal is poured back in on top, which assures good mixing. Analyses of the inoculants and post-inoculants are given in Table III.

Finally the 120 lbs of metal is tapped into a teapot ladle for pouring.

POURING

The castings are poured in the order mentioned previously. Samples for chemical analyses are taken before and after the inoculation. These are 6mm rods obtained with suction bulbs and Vycor tubing. The pouring time for the entire heat has been controlled between 40 and 55 seconds. The pouring temperature range for each heat has been 50°F or less, with a maximum of 2620°F in one heat to a minimum of 2540°F in another.

TEST PROCEDURES

The Y-blocks are sectioned and tensile bars are machined with 0.500" dia. bars obtained from the 1" and 3" Y-blocks while 0.250" dia. bars are cut from the 1/2" Y-blocks. Strain gauges are mounted on the specimens and standard tensile tests are run. The tensile strength, breaking strength, percentage elongation, and percentage reduction in area at the throat and neck are given in Table I. Table II provides the chemical analyses for these heats. Irregularities in strain gauge behavior were noted and the modulus and yield strength values are being checked.

The bottom of the 1/4" Y-block is cut and is bent, as an index of the quality of the modular iron in thin sections. The section is supported on two wedges 1 1/2" apart and a load is applied to the center of the bar through another wedge with a 1/2" radius in contact with the bar. Stress is applied with an arbor press until the bar fails. The bend angle is the total deflection from 180°. As an example, a 40° bend angle indicates each end deflected 20° from the horizontal or no-load position. Since the measurement is taken after failure, the bend angle is a measure of only the plastic deformation capability of the small section. These data are also included in Table I.

Sections are finally cut from the bend samples and the tensile specimens to check for nodularity and nodule count. In these tests, standard 100X photomicrographs are taken and are enlarged to 8" x 10" pictures. At least two are taken from each sample. The total number of nodular and flake graphite particles are counted. The percent nodularity is then the number of nodules divided by the number of nodules plus flakes. The nodule count is obtained by multiplying the number of nodules by 500, which gives nodules per square inch.

Rockwell hardness, Brinell hardness and cooling curve plots are also being prepared.

DISCUSSION

As mentioned in the Summary, the most important results to the present time are the better ductility and nodularity produced by Superseed in the 3-in. Y-block. Specifically, the following values were obtained:

with:	MgFeSi	CeMgFeSi	NiMg
Superseed No. 1	11-8% (.032)	27-15% (.037)	21-11% (.066)
75% FeSi	27-3% (.039)	28-20% (.032)	14- 3% (.11)

(Residual Mg in parentheses)

The 3-in. Y-block is representative of many commercial sections, such as the heavier portions of the automotive crankshaft, and values of elongation below 5% are seriously inferior. While the Superseed gave somewhat lower elongation than 75% FeSi when the inoculant was CeMgFeSi, the absolute value of 15% is certainly adequate. The values of residual magnesium for the iron-base magnesium inoculants appear slightly low, but check analyses by Union Carbide show .041-.045(U.C.) vs. .032 (Chi. Spec.) and .048-.044 (U.C.) vs. .037(Chi. Spec.) Above .04 Mg can be considered adequate.

The reproducibility of the data is being determined by repeating several of these heats. The statistical variations of percent nodularity and nodule count are also being investigated.

Several anomalies should be discussed briefly. In heat number 7, the nodularity varies irregularly with section size and shows improvement in going from the 1-in. to the 3-in. section. This is contrary to the general trend for all the heats and will be checked.

In the higher magnesium content heats, e.g., number 6, the tensile strength increases from the 1/2 to the 1-in. section. This is probably due to massive carbides in the lighter section and is being investigated metallographically.

RECOMMENDATIONS

Based on the data which are now available, it appears that Superseed No. 1 may have an advantage over 75% ferrosilicon in maintaining mechanical properties and nodularity in moderate sections when either MgFeSi or NiMgSi is used as an inoculant. Also, there is certainly no severe poisoning effect by the cerium content.

These indications should be checked by duplicate heats. The role of amount of residual Mg should be evaluated as well.

Experiments should be conducted to determine the amount of Superseed No. 1 which is needed for satisfactory inoculation. Smaller amounts may given satisfactory results and thereby overcome the higher cost per pound.

The fading effects of Superseed and ferrosilicon should be checked because the heavy section data indicate that at slower cooling rates, Superseed is a superior post-inoculant. It may be reasoned therefore that it will provide better resistance to fading.

In addition to the above work, the data should be extended to Superseed No. 2 and SMZ as post-inoculants.

TABLE I

SUMMARY OF HEATS

Heat No.	Inoculant	"Y"Block (inches)	T.S. (psi x 10^3)	B.S. (psi x 10^3)	Elong. (pct.)	R.A.-Throat (pct.)	R.A.-Neck (pct.)	Bend Angle (°)	Nodularity (pct.)	Nodule Count (per in.^{2} x 10^3)
4	CeMgFeSi	1/4	-	-	-	-	-	38	98.7	276
	75% FeSi	1/2	59.8	54.0	28	15.1	24.7	-	97.0	111
		1	61.7	58.4	24.75	11.6	21.6	-	95.7	60
		3	66.4	64.3	19.5	10.4	15.2	-	87.3	36
5	MgFeSi	1/4	-	-	-	-	-	29	96.3	211
	75% FeSi	1/2	63.3	59.8	26.5	13.9	20.5	-	97.4	138
		1	63.8	63.8	14.25	9.6	11.6	-	92.4	96
		3	69.5	69.5	2.5	0.8	1.6	-	63.9	49
6	NiMg	1/4	-	-	-	-	-	11	84.5	137
	75% FeSi	1/2	83.6	81.6	14.0	8.6	11.0	-	93.8	64
		1	107	107	6.75	3.6	4.0	-	96.5	38
		3	89.2	89.2	2.5	0.8	0.8	-	84.4	35

TABLE I Cont'd

SUMMARY OF HEATS

Heat No.	Inoculant	"Y"Block (inches)	T.S. (psi x 10^3)	B.S. (psi x 10^3)	Elong. (pct.)	R.A.-Throat (pct.)	R.A.-Neck (pct.)	Bend Angle (°)	Nodularity (pct.)	Nodule Count (per in.^{2} x 10^3)
7	MgFeSi	1/4	-	-	-	-	-	10	54.5	66
	SS #1	1/2	55.7	55.1	11.0	6.4	9.4	-	89.0	45
		1	54.6	51.0	9.0	4.8	6.8	-	66.9	39
		3	56.1	56.1	8.0	4.0	5.6	-	80.7	34
8	CeMgFeSi	1/4	-	-	-	-	-	32	88.0	150
	SS #1	1/2	62.3	57.0	26.5	15.2	25.2	-	92.1	86
		1	61	50.0	27.25	15.2	24.4	-	96.6	47
		3	66.8	66.8	14.5	8.0	15.2	-	74.8	31
9	NiMg	1/4	-	-	-	-	-	19	96.0	140
	SS #1	1/2	-	-	-	-	-	-	-	-
		1	67.6	64.3	20.75	19.2	21.2	-	88.8	88
		3	82.0	82.0	10.5	6.4	7.6	-	90.9	52

TABLE II

CHEMICAL ANALYSES OF CASTINGS POURED

Heat No.	Inoculant	Post Inoc.	% C	% Si	% Mn	% S	% P	% Mg	% Ni
4	CeMgFeSi	75% FeSi	3.90	2.11	0.39	0.016	0.019	0.032	-
5	MgFeSi	75% FeSi	3.78	2.45	0.40	0.013	0.022	0.039	-
6	NiMg	75% FeSi	3.60	2.39	0.41	0.012	0.023	0.11*	1.12
7	MgFeSi	SS #1	3.76	2.52	0.42	0.017	0.014	0.032*	0.18
8	CeMgFeSi	SS #1	3.76	2.28	0.43	0.017	0.019	0.037*	-
9	NiMg	SS #1	3.70	2.33	0.36	0.012	0.011	0.066	0.50

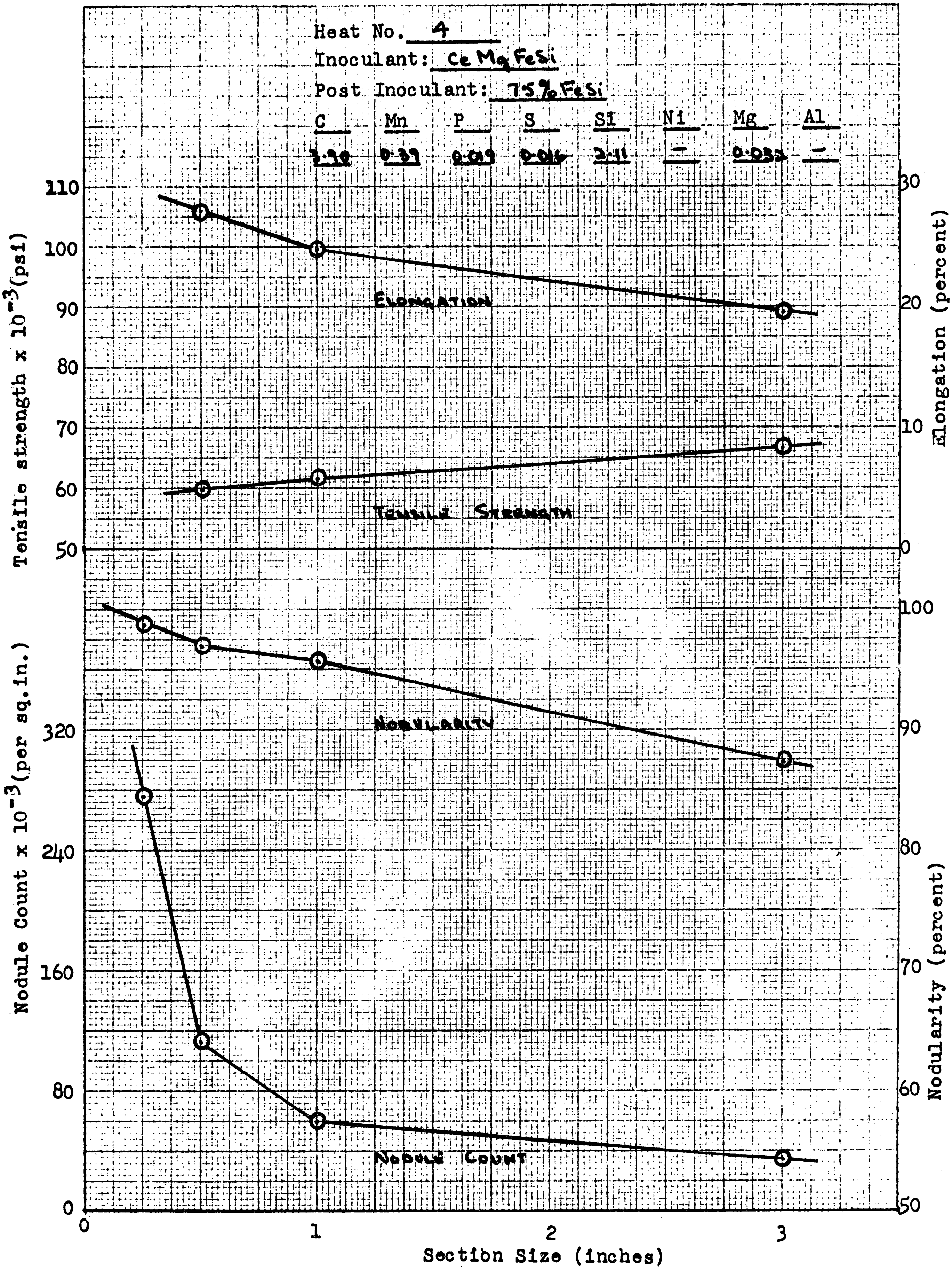
*Magnesium analyses on the same samples have been run independently at the Union Carbide Laboratories and are as follows:

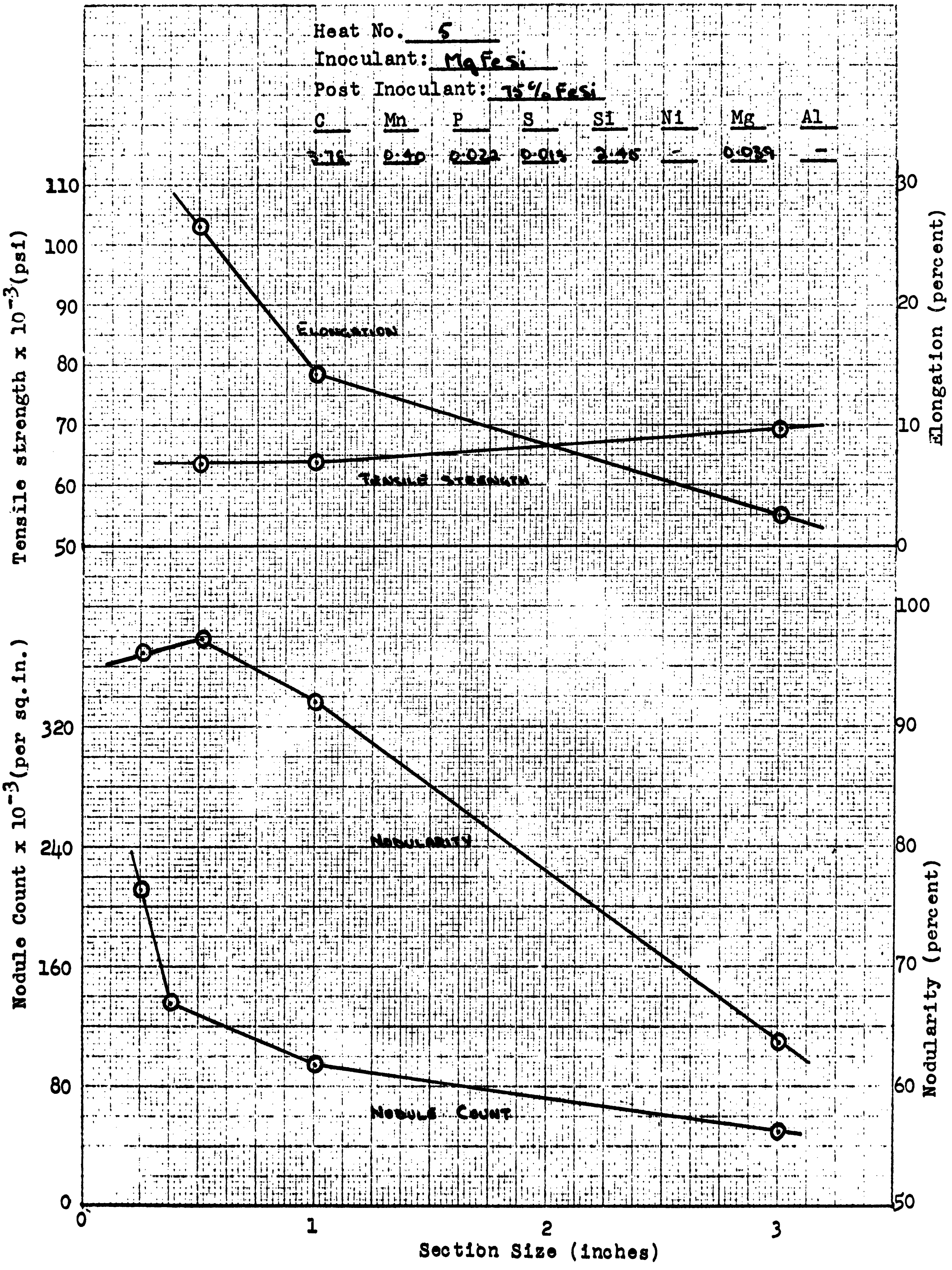
Heat No.	% Mg Analyst 1	Analyst 2
6	0.12	0.12
7	0.045	0.041
8	0.048	0.044

TABLE III

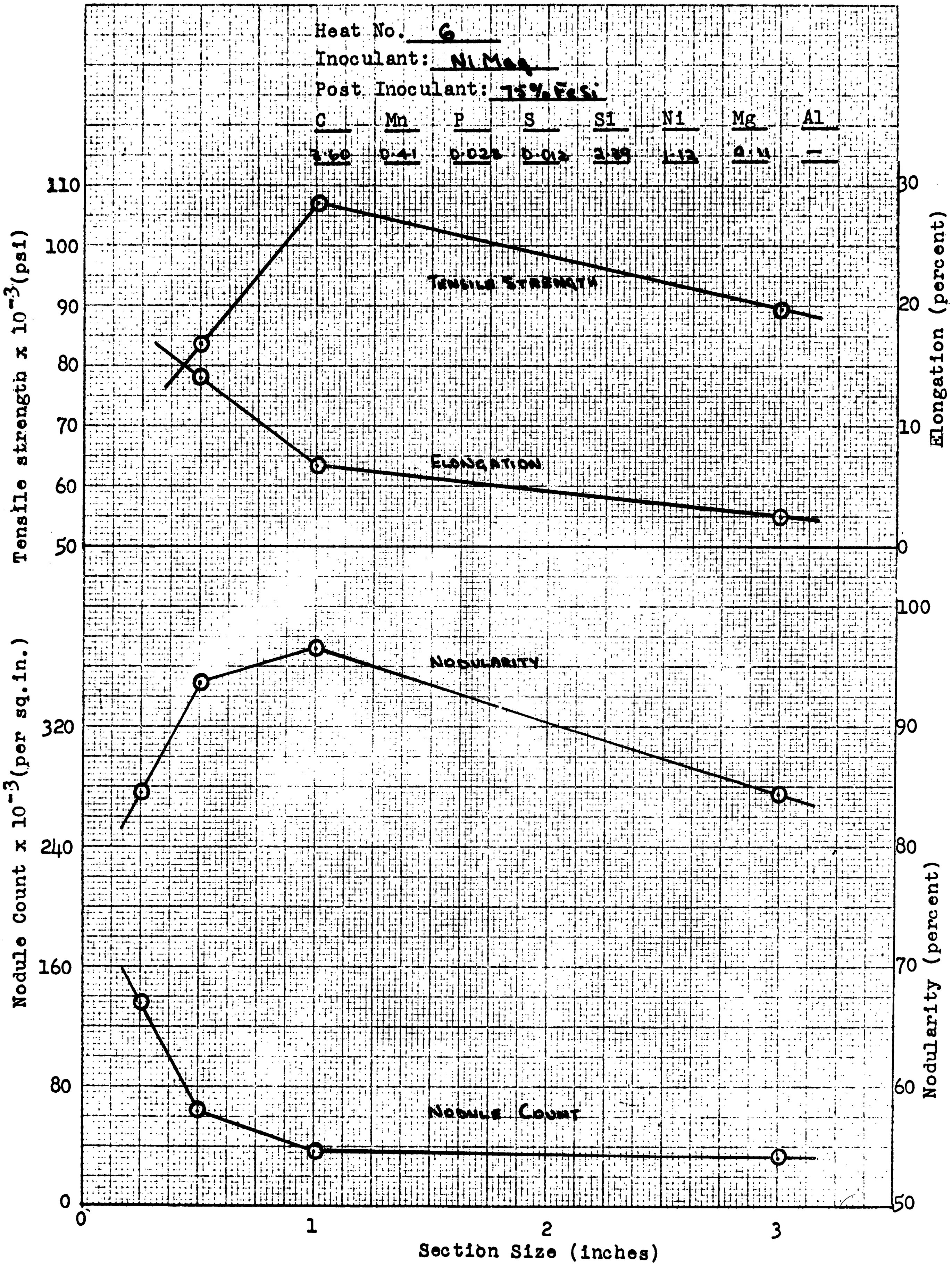
CHEMICAL ANALYSES OF ADDITIONS

Material	% Si	% Mg	% Ca	% Al	% Sr	% Ni	% Ce
CeMgFeSi	48.19	8.60	1.20	0.93	-	-	0.51
MgFeSi	46.52	8.49	1.48	0.75	-	-	-
NiMg(# 2)	31.2	14.65	-	-	-	50.1	-
75% FeSi	75.94	-	1.05	1.30	-	-	-
S.S. No.1	72.13	-	0.09	0.02	1.03	-	-

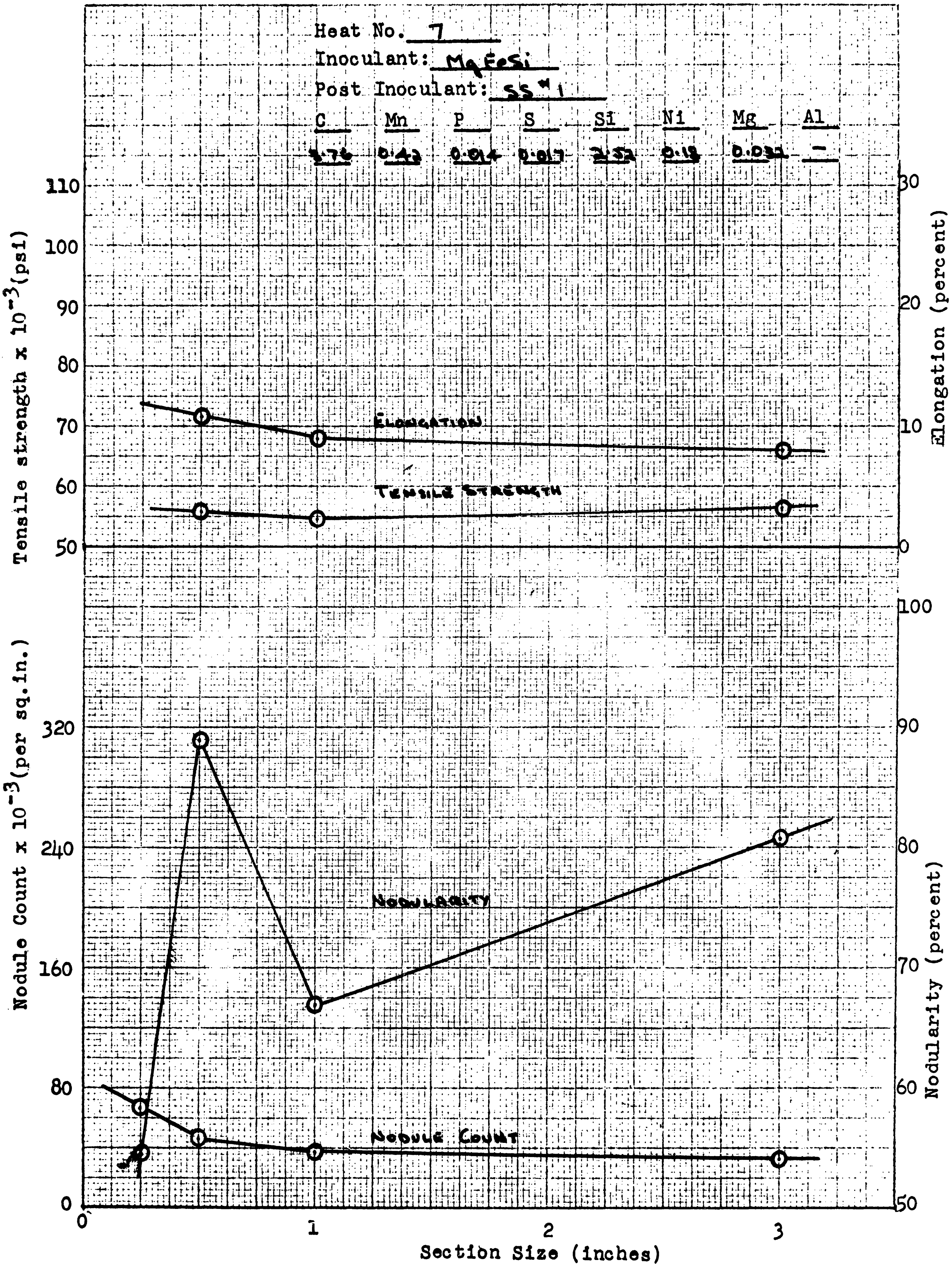

Heat No. 4
Inoculant: Ce Mg FeSi
Post Inoculant: 75% FeSi
C
Mn
P
S
Si
Ni
Mg
Al
3.90
0.39
0.019
2.11
0.032
Elongation
Tensile Strength
Nodularity
Nodule Count
Tensile strength x 10^{-3}(psi)
110
100
90
80
70
60
50
Elongation (percent)
30
20
10
0
Nodule Count x 10^{-3}(per sq.in.)
320
240
160
80
0
Nodularity (percent)
100
90
80
70
60
50
0
1
2
3
Section Size (inches)

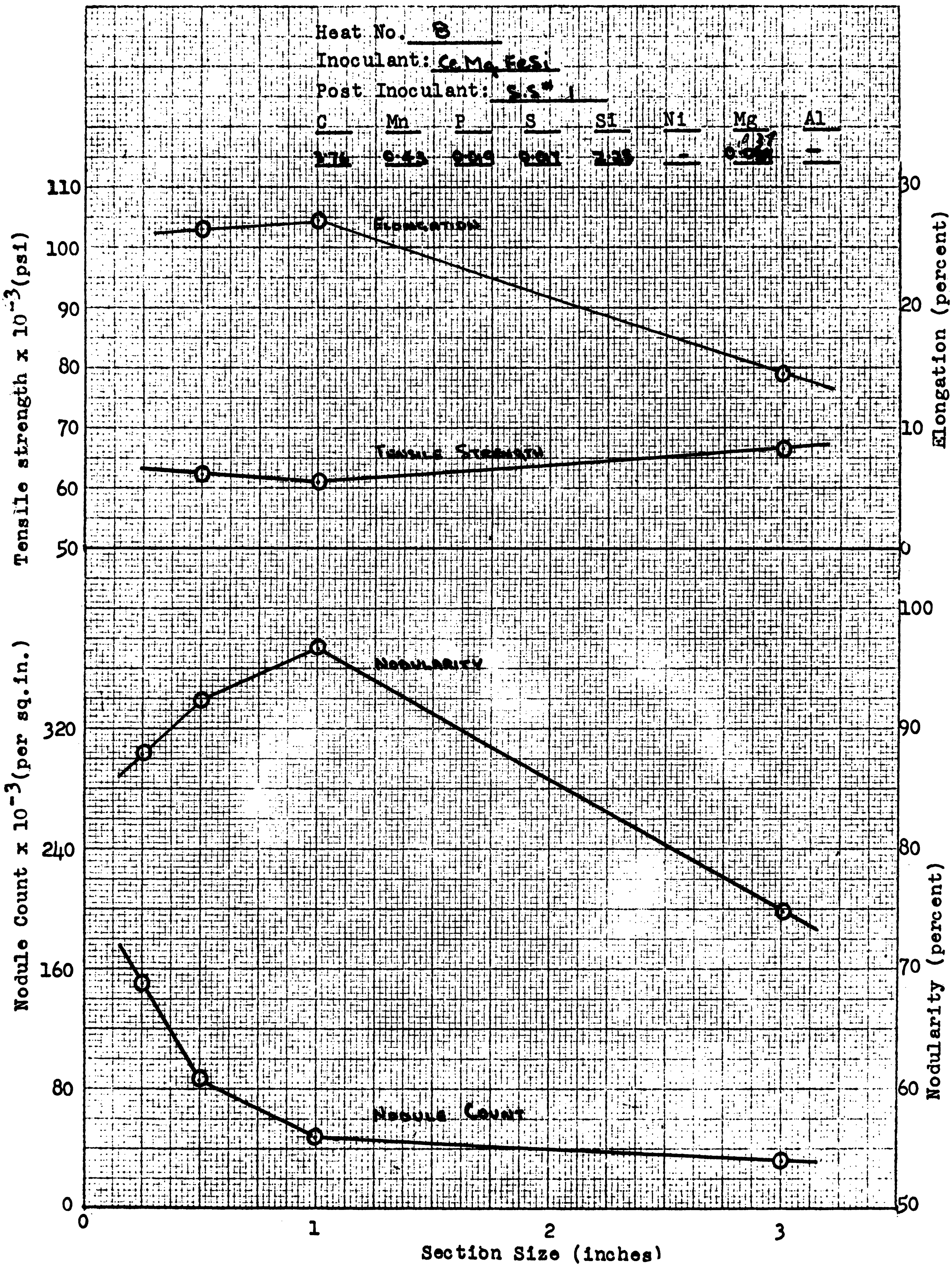


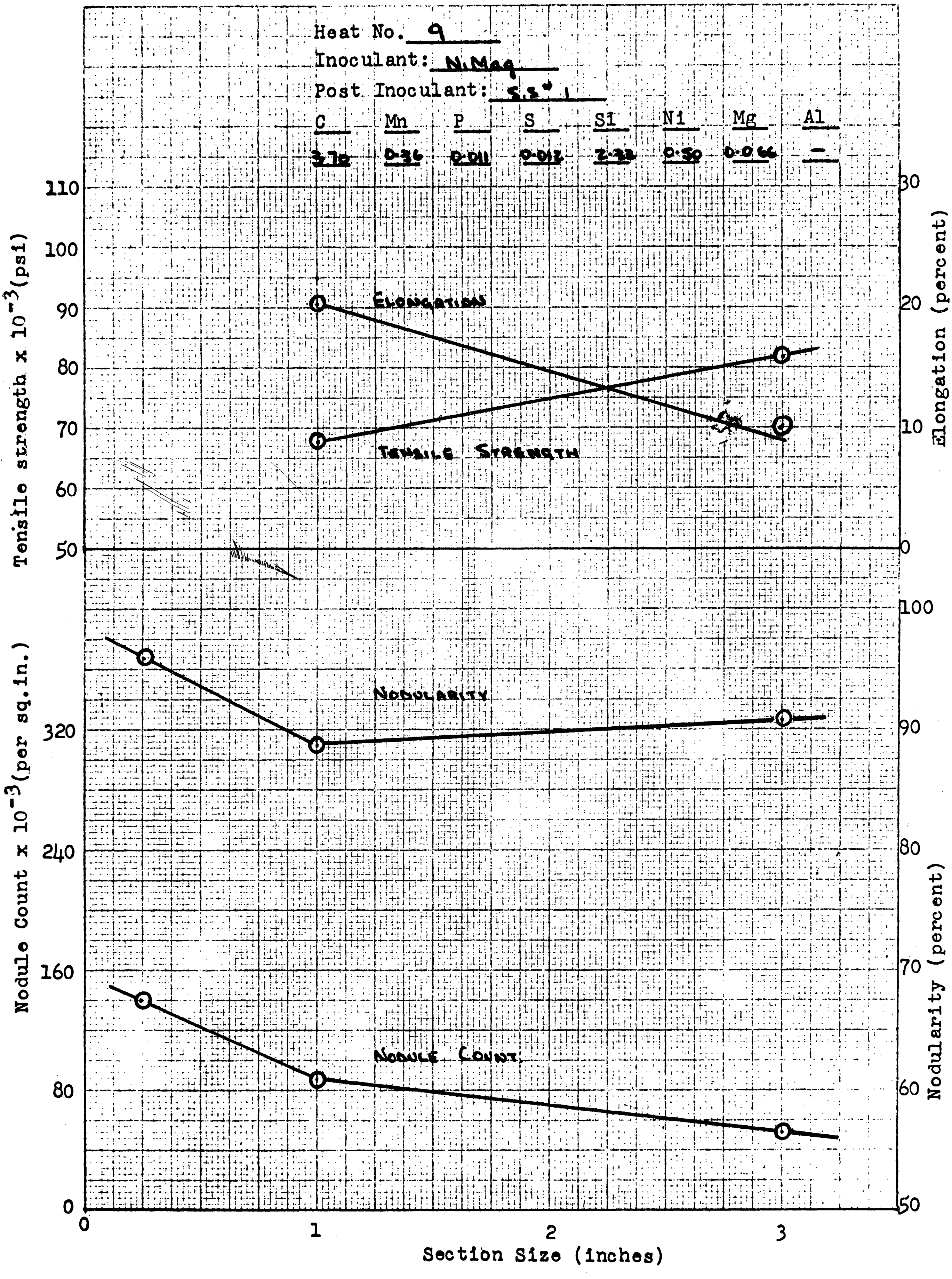
Heat No. 5
Inoculant: MgFeSi
Post Inoculant: 75% FeSi
C Mn P S Si Ni Mg Al
3.76 0.40 0.022 0.013 2.45 - 0.039 -
Tensile strength x 10^-3 (psi)
110
100
90
80
70
60
50
Elongation (percent)
30
20
10
0
ELONGATION
TENSILE STRENGTH
Nodule Count x 10^-3 (per sq.in.)
320
240
160
80
0
Nodularity (percent)
100
90
80
70
60
50
NODULARITY
NODULE COUNT
0
1
2
3
Section Size (inches)



Heat No. 6
Inoculant: Ni Mag.
Post Inoculant: 75% FeSi
C
Mn
P
S
Si
Ni
Mg
Al
3.60
0.41
0.023
0.012
1.12
0.11
—
Tensile strength x 10^{-3} (psi)
Elongation (percent)
110
100
90
80
70
60
50
30
20
10
0
TENSILE STRENGTH
ELONGATION
Nodule Count x 10^{-3} (per sq.in.)
Nodularity (percent)
320
240
160
80
0
100
90
80
70
60
50
NODULARITY
NODULE COUNT
1
2
3
Section Size (inches)


Heat No. 7
Inoculant: MgFeSi
Post Inoculant: SS #1
C 3.76
Mn 0.42
P 0.014
S 0.017
Si 2.52
Ni 0.18
Mg 0.032
Al –
Tensile strength x 10^{-3} (psi)
Elongation (percent)
ELONGATION
TENSILE STRENGTH
Nodule Count x 10^{-3} (per sq. in.)
Nodularity (percent)
NODULARITY
NODULE COUNT
Section Size (inches)


Heat No. B
Inoculant: CeMg FeSi
Post Inoculant: S.S.# 1
C
Mn
P
S
Si
Ni
Mg
Al
0.43
0.019
Elongation
Tensile Strength
Nodularity
Nodule Count
Tensile strength x 10^{-3} (psi)
Elongation (percent)
Nodule Count x 10^{-3} (per sq.in.)
Nodularity (percent)
Section Size (inches)
110
100
90
80
70
60
50
30
20
10
0
100
90
80
70
60
50
320
240
160
80
0
1
2
3


Heat No. 9
Inoculant: NiMag
Post Inoculant: S.S* 1
C Mn P S Si Ni Mg Al
3.70 0.36 0.011 0.012 2.32 0.50 0.066 –
Tensile strength x 10⁻³(psi)
Elongation (percent)
Elongation
Tensile Strength
Nodule Count x 10⁻³(per sq.in.)
Nodularity (percent)
Nodularity
Nodule Count
Section Size (inches)
110
100
90
80
70
60
50
30
20
10
0
320
240
160
80
0
100
90
80
70
60
50
1
2
3