EFFECTS OF SCRAP CHARGES AND OTHER VARIABLES ON THE QUALITY OF IRON CASTINGS: A PROGRESS REPORT

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Abstract

The cast-iron foundry industry has expressed concern regarding the quality of scrap used to prepare iron castings owing to the growth of alloy steel production and its influence on tramp element levels when recycled. Reliable and current information is unavailable on the amount of tramp elements contained in iron castings produced over a significant period of time. Accordingly, the Bureau of Mines is analyzing cast iron samples from participating foundries thoughout the United States on a quarterly basis under a Memorandum of Agreement between the Bureau and the American Foundrymen's Society. Each sample is analyzed for 28 elements to determine if the level of tramp elements in charge materials is changing over time.

Preliminary results indicate that the type of furnace, the geographic location, and the size of the foundry did not significantly affect casting compositions. Owing to the variability of charge materials used, correlation of the analyses of the castings with charge compositions had not been possible. The data obtained are undergoing statistical analysis to determine significant differences among the chemical compositions as a function of time and foundry location.

Introduction

Iron and steel scrap compose over 80 pct of the charge materials used in the production of domestic iron castings. The scrap is derived from such diverse sources as automobiles, pipe, tubing, wire, aircraft, and mechanical equipment. Some users of ferrous scrap in the foundry industry perceive that the nature of this scrap could deteriorate over time. The belief is that ferrous scrap charge materials will contain increasing amounts of tramp elements derived from more alloying constituents entering the metal cycle as scrap is recycled repeatedly. For example, auto makers are paying increasing attention to rust protection and therefore are adding more zinc to car bodies. In addition, greater amounts of alloying elements are used in steels for automotive and other industrial applications. In several years, the automobiles containing these alloying elements will enter the scrap cycle. Small amounts of some alloying elements, such as Al, B, Bi, Cr, Cu, Pb, P, and Sb found in scrap charges are particularly deleterious to the properties of iron castings.

The Charge Materials Committee of the American Foundrymen's Society (AFS) cited the growth of alloy steel production from 1935 to 1975 and projections to 1985 as one reason for the expressed concern. Domestic production of alloy steel increased from approximately 6 pct of total steel production in 1935 to nearly 12 pct in the early 1970's and to over 15 pct in 1980 (table I). A 41-pct increase in alloy steel production was realized from 1970 to 1979 (1). This growth implies that more tramp elements will find their way into the steel scrap recycled to foundries. A small percentage of alloy steel scrap containing detrimental elements such as Al, B, Bi, Cr, Mo, P, Pb, S, and Sb in the charge materials can severely degrade the structure and properties of iron castings, thereby causing waste rejects that cost money, energy, and time. Consequently, foundrymen must use raw materials of known chemistry, devoid of detrimental tramp elements. Poor scrap containing detrimental elements and costing $50 per ton can easily result in the scrapping of castings selling at 30 times the scrap cost. Hence, it is important to control the composition of charge materials. Typically, foundries have purchased scrap without knowing its composition and have produced iron therefrom. In many cases, foundries have purchased premium grades of scrap to avoid tramp elements. However, the supply of premium scrap is expected to decline. In addition, specifications for castings are becoming more stringent as demand for higher quality products increases.

TABLE I. Alloy and stainless steel production

Year	Pct of steel production
1935....	~6
1965....	11.2
1975....	14.0
1980....	15.3

Since 1929, the American Iron and Steel Institute (AISI) has conducted surveys to obtain information on the Cr, Cu, Ni, and Sn contents of raw steel. Comparative results for 1954, 1962, and 1977 in an unpublished report showed a decrease in Cu, Ni, and Sn from 1954 to 1962, with levels in 1977 remaining approximately equal to those in 1962 (table II). However, the Cr content was significantly higher in 1977 than in the previous survey years. This trend on a limited number of tramp elements in steel may reflect use of more premium scrap, better scrap segregation and separation, and/or better tramp element control (1-2).

TABLE II. Tramp element content of steels

Year	Cr	Cu	Ni	Sn
1954....	0.048	0.122	0.062	0.016
1962....	.038	.082	.043	.008
1977....	.063	.087	.051	.007

In other unpublished studies, a comparison of steels made from production-grade scrap in 1965 and 1977 showed little difference in composition. Physical beneficiation procedures can upgrade such scrap to decrease the tramp element contents (3).

The foregoing data are fragmentary at best (4) since (1) steel scrap grades and compositions usually consumed by domestic iron foundries are different from those melted by nonintegrated steel mills, (2) geographic differences in scrap often are pronounced, and (3) alloying of cast iron products has increased. Reliable and current information is not available on the precise amount of tramp elements contained in ferrous castings made over a significant period of time. To supply this information, the AFS asked the Bureau of Mines to participate in a study to obtain reliable analytical data on samples of iron castings from a variety of domestic foundries over a period of time. An ad hoc committee was appointed from the AFS Charge Materials Committee to monitor the work. The ad hoc committee met to determine (1) regions of scrap supply, (2) satisfactory and uniform sampling procedures, (3) charge information needed, and (4) types of foundries. Initially, 47 companies expressed interest in participating in the study with gray and ductile iron samples.

Accordingly, a Memorandum of Agreement was signed on July 23, 1980, by the Bureau of Mines and the AFS which provided that the AFS collect 55 to 70 samples and charge information from a representative number of foundries on a quarterly basis and submit these samples to the Bureau for analyses. Since then, three annual extensions to the original Memorandum of Agreement have been signed. The Analytical Laboratory at the Bureau's Albany (Oregon) Research Center conducts the analyses and reports the results to the AFS. Correlation of the analyses with charge materials, furnaces used, and foundry size and location over a sufficient period of time (5 to 10 yr) involves a joint Bureau-AFS effort. Results should delineate the effect of these factors on the quality of iron castings and should enable the domestic foundry industry to take corrective action, if necessary, in time to avert costly waste.

The objective of this investigation is to determine whether the tramp levels in charge materials are changing over time as reflected in the compositions of the castings and, if so, whether the aforementioned input variables can be cited as causes. This paper presents an interim report on the analytical data for the first 3 yr of this study.

Sampling Procedures

Each participating foundry purchased or made an open copper mold into which the casting samples were to be poured. The mold (shown in figure 1) tapers from 1-1/2 inches ID at the top to 1.38 inches ID at the bottom and is 1/2 inch deep. Representative slag-free and well-mixed samples were taken before any alloy or inoculant was added. The analytical sample was the first poured from the spoonful of metal that filled the mold with no misruns, cracks, or inclusions. The sample was cooled in the mold before water quenching to prevent cracking. A typical as-received sample is shown in figure 2.

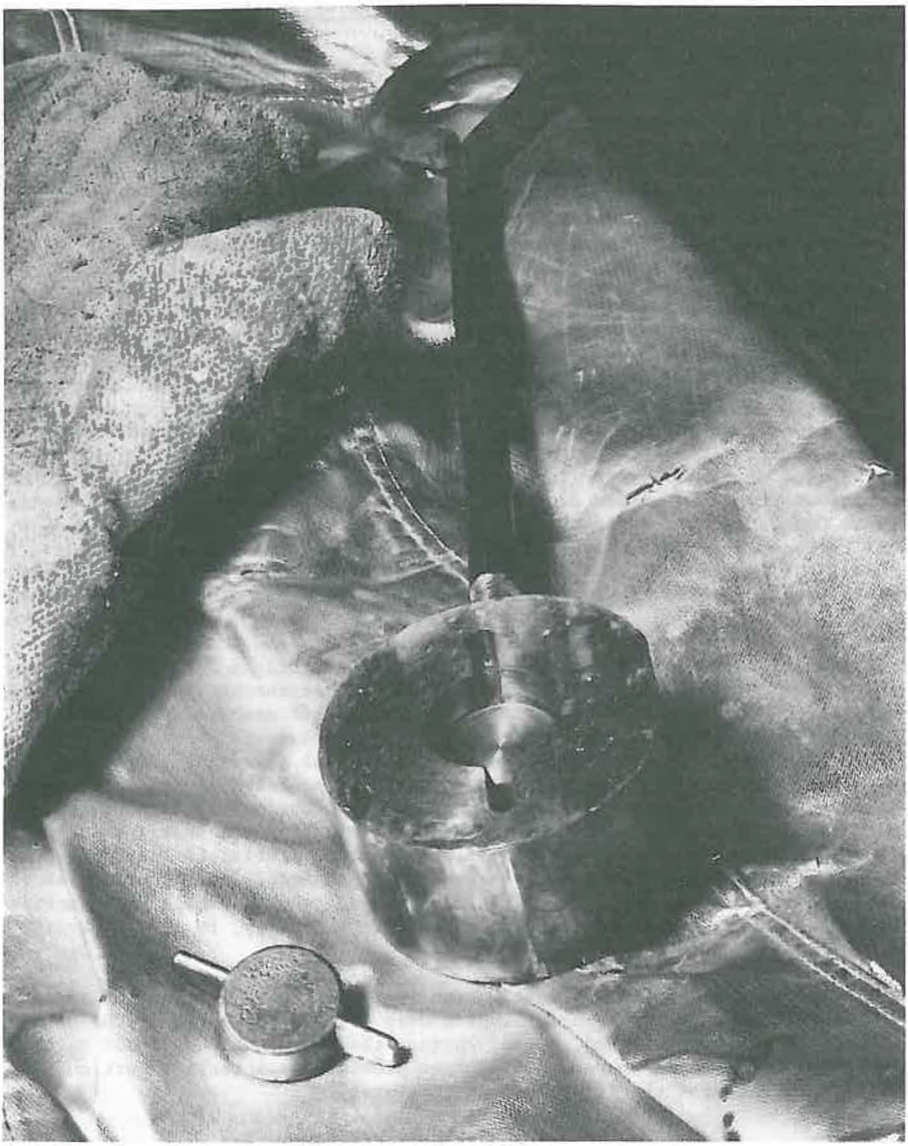

Figure 1 - Standard oxygen-free bus bar copper mold used for iron samples poured by participating foundries.

Figure 2 - Cast iron samples used for analyses: as-received sample (left), foundry-analyzed sample with "ears" removed (center), and polished sample ready for analysis (right).

Participating foundries were classified into six geographic-marketing regions: (1) Pittsburgh-Philadelphia-New England, (2) Detroit-Toledo-Cleveland, (3) Birmingham-Chattanooga, (4) Chicago-Milwaukee-Gary, (5) St. Louis-Western, and (6) Far West. The geographic regions are shown in figure 3.[1]

The present charge sheet used by the participating foundries is shown in figure 4. Beginning with the fifth group of samples, each foundry was encouraged to analyze a sample from the same heat in its own analytical laboratory before submission to the AFS headquarters. Analyses were received from participating foundries on 53 pct of the samples, of which 19 pct were conducted on the same sample. Foundries supplied analyses on 62 to 76 pct of the samples in succeeding groups. This procedure provides a direct comparison of analyses and should eliminate sampling variables.

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[1] Foundries in region 6 (fig. 3) have been added to the study only recently.

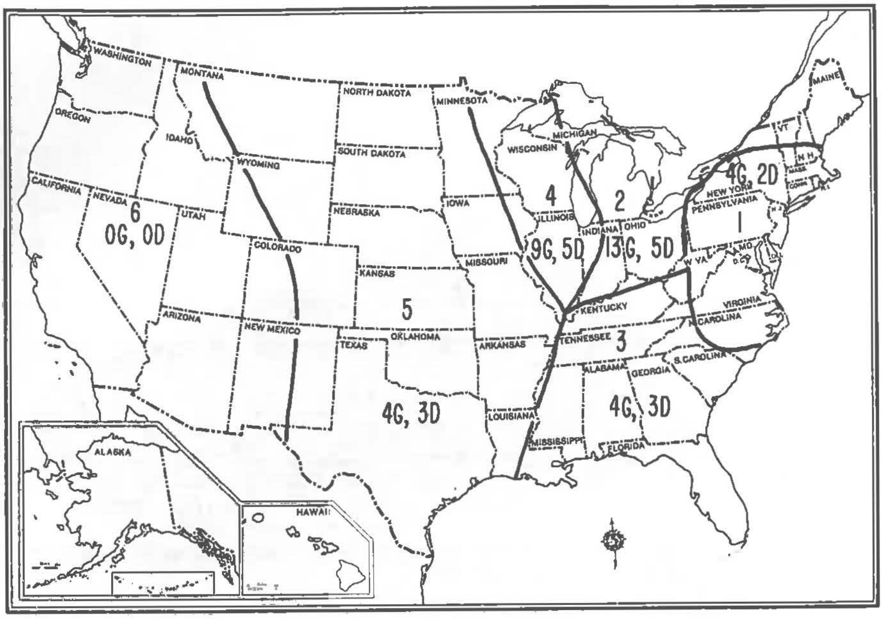

Figure 3 - Geographic-marketing regions for foundries participating in this study. The average number of samples of gray (G) and ductile (D) iron submitted during each quarter is indicated for each region.

Sample Preparation

After the samples were received from the AFS headquarters, the two "ears" on each were removed (fig. 2) and ground to minus 65 mesh using a steel mortar and pestle to which an airhammer was attached. This material was used for atomic absorption determinations on some of the elements that could not be determined on the direct-reading spectrograph owing to line interference, lack of sensitivity, or lack of appropriate standards. The surface of the sample to be analyzed was ground on a LECO SG-50[2] swing grinder using an aluminum oxide grinding wheel of approximately 80 grit for analysis by the direct-reading spectrograph.

Analytical Procedures

Each prepared sample was analyzed on a Jarrell-Ash Atomcomp 750 vacuum direct-reading spectrograph equipped with a Mark II Computer configuration. Twenty-eight elements[3] were determined in each sample, of which 20 were run on the direct-reading spectrograph. Standardization of the instrument was accomplished through the use of Brammer standards, with some verification using NBS standards. Eight elements were determined using atomic absorption spectroscopy on a Perkin-Elmer 4000 Atomic Absorption Spectrophotometer. Of these eight, five (As, Se, Te, Sb, Bi) were run by graphite furnace atomic absorption and three (Cd, Zn, Pb) by flame atomic absorption. A LECO CS-144 automatic simultaneous carbon-sulfur analyzer was used to determine C and S

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[2] Reference to specific makes or models of equipment is made to facilitate understanding and does not imply endorsement by the Bureau of Mines.

[3] The elements were Al, As, B, Bi, C, Cb, Cd, Ce, Co, Cr, Cu, Mg, Mn, Mo, Ni, P, Pb, S, Sb, Se, Si, Sn, Te, Ti, V, W, Zn, and Zr.

AFS-USBM CHEMISTRY TRACKING PROJECT

	METAL	QUARTER	YEAR	CODE NO.
SAMPLE SERIAL NO.				

1. GRADES PRODUCES FROM THIS BASE IRON
CLASS 25____30____35____40____OTHER____

CHEMICAL ANALYSIS OF SAMPLE IF AVAILABLE

			DUCTILE	AS CAST	HEAT TREATED
C ______	Cr ______	60-40-18			
Si ______	Mo ______	65-45-12			
Mn ______	Ni ______	80-55-06			
P ______	Cu ______	100-70-03			
S ______	Ti ______	OTHER			

2. FURNACE TYPE AND MELT RATE USED TO MELT SAMPLE

CUPOLA _____(T/HR) IND. _____(T/HR) ARC _____(T/HR) OTHER _____(T/HR)

3. TOTAL SHOP MELT RATE CLASSIFICATION (CHECK ONE)

A) 1,000 TONS/MO. OR LESS ____________
B) 1,000-8,000 TONS/MO. ____________
C) OVER 8,000 TONS/MO. ____________

I.S.I.S. CODE NO.	4. CHARGE MAKE-UP MATERIAL	% OF TOTAL CHARGE METALLICS	CHANGE SINCE LAST REPORT (YES/NO)
	FOUNDRY RETURNS....................	%	
	STEEL SCRAP		
	BUNDLES #1_____ #2_____ OTHER_____	%	
	BUSHELINGS........................	%	
	PLATE & STRUCTURAL................	%	
	SHREDDED AUTOMOTIVE...............	%	
	PUNCHINGS.........................	%	
	TURNINGS..........................	%	
	IRON SCRAP		
	PURCHASED CAST....................	%	
	BORINGS...........................	%	
	OTHER ______________________	%	
	PIG IRON - TYPE (______________)	%	
	DIRECT REDUCED IRON...............	%	
	FERROALLOYS TYPE (______________)	%	
	FERROALLOYS TYPE (______________)	%	
	TOTAL	%	

Figure 4 - Replica of charge sheet used by participating foundries.

when these elements exceeded the standardization range for the direct-reading spectrograph. Twenty-two of these elements were chosen as those thought to be the most detrimental to iron castings (5). Six elements were added at the request of several foundrymen.

Results

Analytical Data and Trends

To date, 12 groups representing 12 quarters (3 yr) each of approximately 38 to 55 ductile and gray iron samples have been analyzed. In all of the groups, at least eight elements were not detected. These elements and their lower limits of detection (in parentheses, weight percent) were Bi (0.01), Cb (0.01), Cd (0.005), Ce (0.02), Sb (0.02), Se (0.01), Te (0.005), and Zr (0.01). For all of the other elements, neither the type of furnace used nor the geographic location nor size of the foundry had an apparent significant effect on the compositions of the castings in all groups.

In the first group, the Pb contents in all but one gray iron sample ranged from 0.005 to 0.011 wt pct, which is higher than that typically observed in gray and ductile iron (0.001 to 0.004 wt pct) (5-6). In addition, all ductile iron samples contained more Pb than normal. Lead is considered to be among those elements having the highest estimated degree of future threat to the quality of ferrous castings (1-2). The eight elements mentioned above and W were not detected. Sulfur was present above the usually observed levels in half of the ductile iron samples.

Analyses from the second group showed that only six samples (two ductile iron and four gray iron) possessed higher than normal Pb contents. The same eight aforementioned elements and W were not detected. Only one other gray iron sample from this group had a higher than usual Ti level.

In the third group of samples, the same eight elements were not detected. In addition, Pb was not detected in all but one gray iron sample. Again, one gray iron sample in this group (from a different foundry than that in the second group) had a greater than normal Ti level, and over half of the ductile iron samples possessed S contents above those usually observed in iron castings.

Analytical results from both the fourth and fifth groups of samples showed that the eight elements mentioned previously, as well as Pb and W, were undetected. In the fourth group, only Ti in one gray iron sample and S in over half of the ductile iron samples were present in amounts greater than those usually observed. One gray iron sample contained more Cr than normally noted. This element represents a very high degree of future threat to the quality of iron castings (5-6).

Results from the fifth group again showed one gray iron sample having more than the normal levels of Ti (from the same foundry as that noted in the fourth group). Again, over half of the ductile iron samples had higher than normal contents of S. One ductile iron sample had more P than expected.

In the 6th through 12th groups of castings, all 10 elements mentioned previously as not being detected in the fourth and fifth groups again were not detected, with the exception of Te in one gray iron sample from the same foundry in both the 9th and 10th groups. Results from the samples in groups 6 through 12 showed that the especially deleterious tramp elements are present in concentrations generally within the expected ranges (5-6). A few random exceptions include Ti in one gray iron sample from group 6; Cr in one to two ductile iron samples from groups 6, 8, 9, 11, and 12; and Pb in one gray iron sample from group 8. Sulfur was present at higher than normal levels in many ductile iron samples from groups 6 through 9 and 11.

For elements that are either considered especially deleterious to iron castings or others of concern and for which specific analytical values are available, mean values were calculated and subsequently plotted as a function of time for both gray and ductile iron for each quarter. These plots are shown in figures 5 and 6, together with an indication of the precision of the data as expressed by one standard deviation (vertical lines). Although random variations can be noted, trends over a 3-yr period do not appear significant with the exception of Co (decreased after 1 yr) and Sn (increased after 1 yr). In addition, Pb also decreased significantly during the first year, although this element was not plotted in the figures since it was not detected in many samples.

Comparison of Bureau and Foundry Analyses

Scattered independent analyses were received from a few foundries for groups one through four for comparison purposes. Generally, the results correlated satisfactorily with the Bureau analyses.

Beginning with the fifth group of samples, the foundries were given an opportunity to supply their own analyses from the same heat on the charge sheets for the first time (fig. 4). In general, the Bureau's analyses for this group correlated well with those supplied by the participating foundries. Only Si showed what might be significant differences between the Bureau's analyses and those of the foundries (especially in the ductile iron samples). This does not imply that either the Bureau's or the foundries' analyses are necessarily incorrect. Differences in standards used and/or the use of different analyzed samples from the same heat may be responsible for the observed differences. In some cases, the foundries and the Bureau analyzed the same sample. Whether or not the same sample was analyzed had no apparent significant impact on the observed differences in analyses for all groups.

Correlation of Results With Input Variables

Observations on Analytical Data

Observations of the analytical data indicate that there is no apparent correlation between the charge materials used and the compositions of the castings. With respect to the geographic locations of the foundries, random anomalies were noted. Particularly noteworthy was the tendency of foundries located in the Southeastern United States to produce castings having higher levels of As than typically observed.

Computerized Data Base and Averaged Data

Quarterly mean values for each element were calculated for both ductile and gray iron samples within each geographic region. These calculations were derived with a computer using dBase II. A listing of these averages for successive quarters in each region provided an indication of the trends for the analyses as a function of time. No averages were calculated for an element when it was not detected in any quarter. For some elements that in some cases were not detected, averages were calculated only from actual analytical values given. The average values in these cases were not included when considering trends.

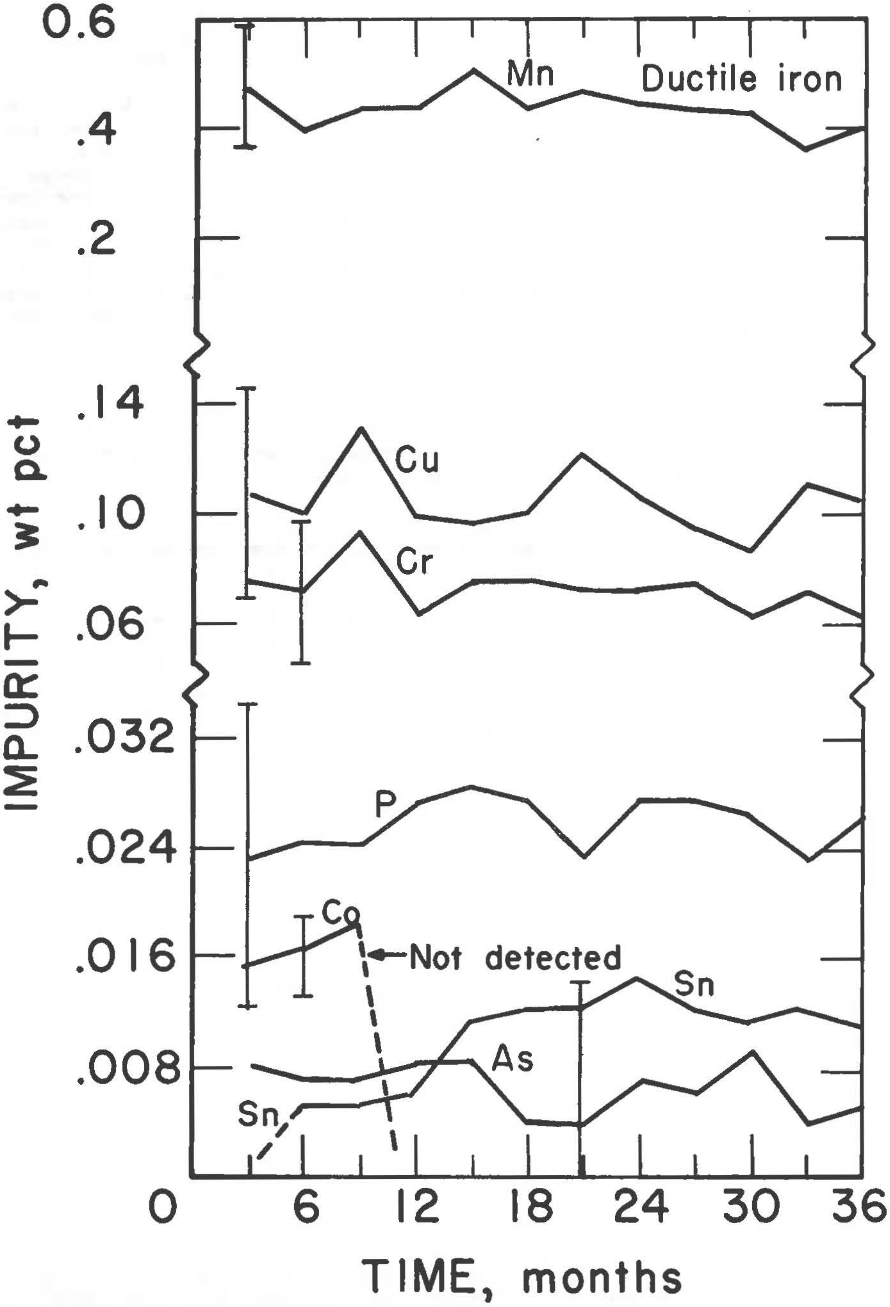

Figure 5 - Trends in analyses of some detrimental elements in ductile iron over a 3-yr period.

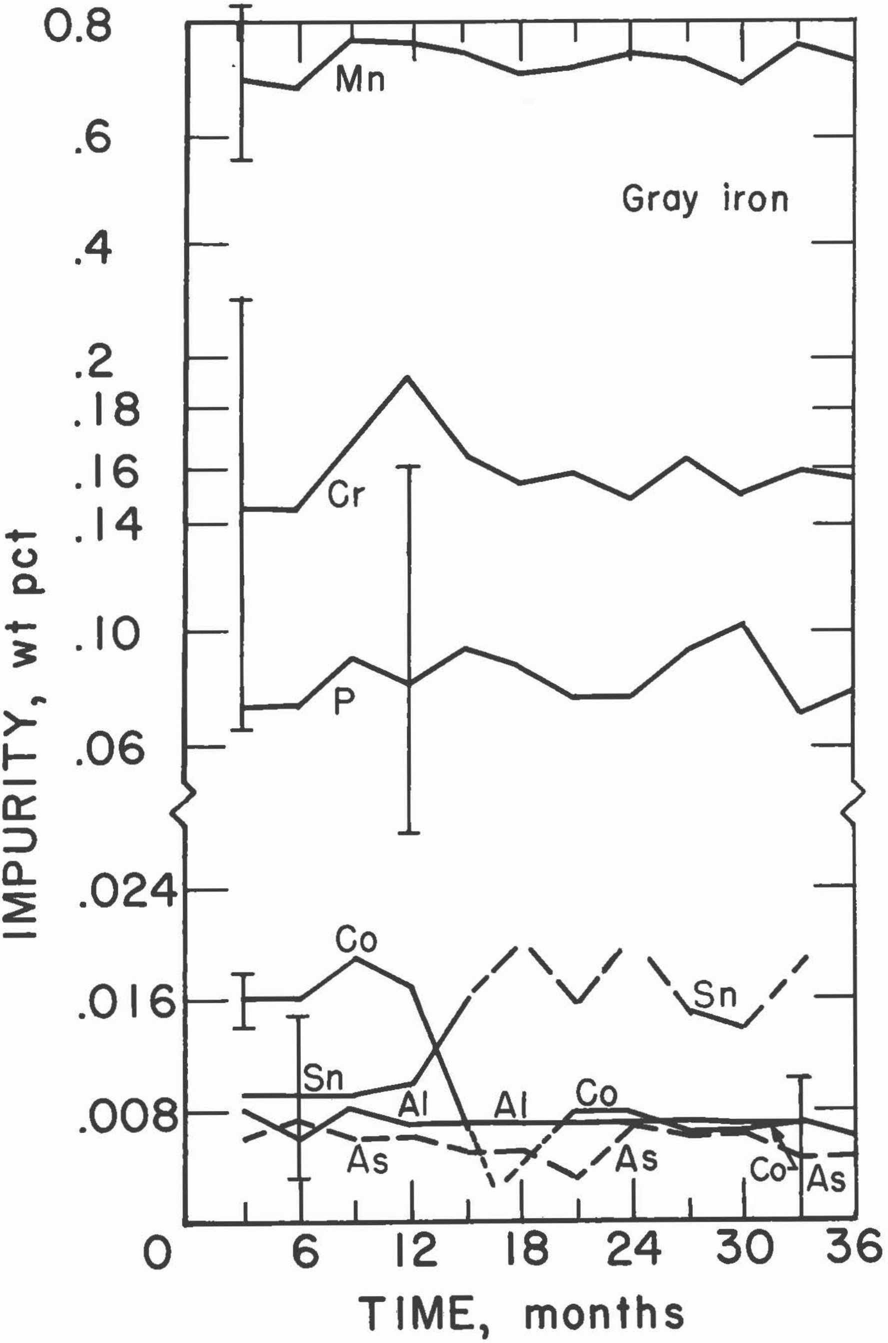

Figure 6 - Trends in analyses of some detrimental elements in gray iron over a 3-yr period.

Among the tramp elements considered especially deleterious to cast iron, the averages indicate an increase in P in ductile iron samples from the upper Midwest, decreases in Pb in samples from all five geographic regions, and decreases in P in samples from the Southeast as a function of time. For gray iron, apparent increases in B in samples from the Northeast, Great Lakes, and upper Midwest regions, and P in samples from the Northeast were indicated. Apparent decreases in Pb in samples from all regions, P in samples from the Southeast, and possibly Cr in samples from the Northeast and Great Lakes regions were observed. Based on observations of the average analyses, possible trends for other less detrimental elements are presented in table III.

TABLE III. Possible Trends for Tramp Elements in Iron Castings Over 3 Yr

Region	Ductile iron		Gray iron	
	Increase	Decrease	Increase	Decrease
Northeast......	Al(?), Sn(?)	Co(?), Mn	S, Ti(?)	Co, Zn(?)
Great Lakes....	Sn	Co	Sn(?)	Ti(?)
Southeast......	Mg(?), Sn	Co(?)	Mg, Sn	As(?), Co(?), S, Ti
Upper Midwest..	Sn(?)	Co	Sn(?)	Co
West...........	Zn(?)	Co(?), Cr(?)	None	Co, Ti

? denotes uncertainty.

For ductile iron, observations of the grouped data within each quarter indicate that As and P occur at higher levels than the grouped averages in one-half or more of the samples submitted from foundries located in the Southeastern United States. The same observation was made for C in ductile iron samples from the Western United States. Gray iron samples showed P and Ti present in greater levels than the grouped averages in one-half or more of the samples from the Northeastern United States, and As, Co, and S occurred at higher levels in samples from the Southeastern United States. Titanium contents were lower than the grouped averages in over one-half of the gray iron samples from the Western United States.

Statistical Analyses

With the large amount of analytical data generated, a rigorous correlation of the results with the charge materials and with the other input variables (geographic location and size of the foundries, and types of furnaces used) suggest the need for a statistical evaluation. Some of the questions that require answers are as follows:

1. What are the relations of charge compositions within and between geographic regions?

2. What (if any) are the trends in the analyses as a function of time?

3. What are the relations between each element and every other element determined?

4. What are the relations between each element determined and the input variables on the charge sheets (fig. 3) both within each geographic region and quarterly group and between each region and group?

A preliminary statistical evaluation of the analytical data obtained from the first four quarterly groups of iron casting samples was conducted by QIT-Fer et Titane, Inc. This work was designed to determine (1) whether the regional geographic location of the participating foundries had a significant effect on selected tramp elements, and (2) whether any significant differences could be ascertained among the analyses as a function of foundry location within each of five geographic regions. Elements that were not detected, as well as C and Si, were not included in this evaluation. Only 40 samples from foundries that contributed in each of the four quarters were considered.

The overall results for 1 yr indicate that the geographic location of the foundries both between and within the regions failed to affect the analyses of either gray or ductile iron samples.[4] However, a few localized significant variations occurred with respect to a single region or quarter. These variations are summarized in tables IV and V. In both tables, the term "average" refers to the mean value for all the elements considered in the statistical evaluation.

TABLE IV. Significant variations in the elemental analyses of iron castings within geographic regions as a function of time[1]

	Gray iron					Ductile iron				
Region...	1	2	3	4	5[2]	1	2[3]	3	4	5[3]
1st qtr..	<Co								<Sn	
2d qtr...				<Co						
3d qtr...		>Co	<Sn	>Cr >Ni		>P				
4th qtr..		>B	>B >Co <Ni	>B <Ni				>Sn		

> Denotes above average for indicated elements.

< Denotes below average for indicated elements.

[1] No significant differences for elements not listed (see footnotes 2 and 3.

[2] No significant differences for Al, As, B, Co, Cr, Cu, Mn, Mo, Ni, P, S, Sn, and Ti.

[3] No significant differences for Al, As, Co, Cr, Cu, Mn, Mo, Ni, P, S, Sn, and Ti.

TABLE V. Significant variations in the elemental analyses of iron castings between geographic regions

Region	Gray iron[1]	Ductile iron[2]
1.....	<Cr, <S	>Cu, <Ni, <S
2.....	>Mo[3], >Ni[3]	None.
3.....	>As, >P	<Al, >As
4.....	>Al	>Mn, <P, >S

> Denotes above average for indicated element.

< Denotes below average for indicated element.

[1] Variations in the concentration of B, Co, Mn, Sn, and Ti are insignificant.

[2] Variations in the concentration of Cr, Mo, Sn, and Ti are insignificant.

[3] Highly variable.

Attempts to statistically correlate the analyses with charge material compositions in this preliminary evaluation were unsuccessful owing to the wide variations in charge materials, which produced standard deviations exceeding mean values for any one type of charge material in many cases.

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[4] At the 95-pct confidence level.

A statistical analysis has begun on the data for the first 3 yr. At present, the data from the computerized data base are undergoing an analysis of variance to determine any significant effects of time and geographic location of the foundries. Those elements that were either not detected or were present at levels greater than the upper limit of detection are not considered in this statistical analysis. After any significant differences have been identified, an attempt will be made to correlate these differences with the charge materials as reported on the charge sheets by the participating foundries. In addition, significant trends over the entire time period will be identified.

Summary and Conclusions

Compositions of iron castings from 12 groups of samples submitted quarterly by foundries throughout the United States generally show no apparent correlation either with the furnace used or with the geographic location and size of the foundry. Attempts at correlating the analyses with the charge compositions have been difficult owing to the wide variety of charge materials. No apparent correlation is evident. Changes in the compositions of the castings have been minimal over the time period that this study has been in progress. Cobalt, lead, and phosphorus levels apparently have decreased, and tin contents evidently have increased over this period, but no significant trends can be attached to the levels of any of the elements over this relatively short period of time in the absence of a rigorous statistical evaluation.

Mean values for each element within each geographic region showed some indication of trends for P and Pb with respect to time for ductile iron and for B, P, Pb, and possibly Cr for gray iron. For the mean values within each quarter, As and P may be anomalously high in ductile iron samples from foundries located in the Southeastern United States. The same was true for As, Co, and S in gray iron samples from the same region, and for P and Ti in samples for the Northeastern United States.

The 3-yr analytical data are presently undergoing a rigorous statistical analysis in an attempt to quantitatively determine any significant effects of time and foundry location on the analyses. Overall trends and possible correlations with charge materials then will be evaluated.

In the later groups of samples, over half of the foundries submitted their own analyses on castings from the same heat for comparison purposes. These analyses generally agree well with those of the Bureau. Some differences in Si contents, especially in ductile iron samples, may be due to the use of different standards and/or the use of different analyzed samples from the same heat by the Bureau and the foundries. Liaison between Bureau analysts and those of the foundries should resolve the apparent differences. No significant differences were noted as a function of whether or not the same sample was analyzed by both the Bureau and the relevant foundry.

It is concluded that additional data over a longer period of time will be required before reliable conclusions can be reached with respect to the changing quality of iron castings. Results thus far represent the solid, quantitative beginning needed to obtain reliable and current baseline data so that domestic foundrymen will have the required data to take effective action.

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RECYCLE AND SECONDARY RECOVERY OF METALS

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