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SORTING TECHNIQUES FOR MIXED METAL SCRAP

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Abstract—The U.S. Bureau of Mines is conducting research on methods for sorting and identifying mixed metal scrap so that this resource can be better utilized. A mechanical method for separating wrought and cast aluminum scrap and instrumental methods for identifying mixed aluminum scrap and mixed high-value scrap are reviewed. New research on spark testing and field experience in high-value scrap sorting are discussed.

INTRODUCTION

For scrap to be recycled, it must be sorted into groups that contain similar materials. This separation may be done by machines or experienced scrap sorters or both. Water elutriators, heavy media separators, and "aluminum magnets" can produce aluminum alloy concentrates suitable for recycling from such diverse sources as automobile shredders, municipal solid waste processing plants, and incinerators[1]. Experienced scrap sorters, using object recognition, spark tests, chemical spot tests, color, apparent density, and magnetic properties, can adequately sort a wide variety of alloy groups[2].

However, the complex nature of new materials entering the scrap market has made sorting more difficult and expensive. Many alloys contain so many components that separation as discrete alloys becomes a prerequisite for effective recycling. There are often complicated tradeoffs, and the amount of sorting done is dependent on the premium paid for better segregated material. This premium tends to increase as the inherent value of the scrap increases. For example, based on recent *American Metal Market* quotes, the wrought fraction of mixed aluminum scrap has a value of a few cents per pound more than the mixed scrap. Segregated superalloys have a value of at least $1 per pound more than mixed stainless steel – superalloy scrap. Development of sorting technology appropriate to the diverse needs of the scrap industry will result in increased materials conservation. The Bureau of Mines is conducting research to improve recycling efficiency by introducing new technology to identify and sort scrap metals. This paper describes recent Bureau research on separation of aluminum[3,4] and high-value scrap[5,6].

ALUMINUM SCRAP

In 1983, 1.7 billion lb of old aluminum scrap was recycled in the United States[7]. However, it is estimated that only 25 – 30% of available old aluminum scrap is recycled each year[8]. Recycling of scrap aluminum poses several technical problems to the secondary ingot maker. Because of its high chemical activity, aluminum cannot be refined by pyrometallurgical techniques such as those used for scrap copper or iron. Therefore, the recycling of mixed aluminum scrap into a specific alloy is accomplished through blending and dilution.

Scrap aluminum may be broadly characterized as either wrought alloys or cast alloys. Wrought alloys contain low percentages of alloying elements; that is, alloying elements total

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less than about 4%. Casting alloys contain the same elements as wrought, but in greater amounts; for example, the silicon content in cast alloys can range up to 22%. Owing to the tight compositional limits for wrought alloys, the secondary aluminum industry remains primarily a supplier of casting alloys. Exclusive of used beverage can recycling, which represents the special case of a source-separated scrap, in 1983, 79% of secondary aluminum production was used for casting alloys, 14% for wrought extrusion billets, 4% for steel deoxidizers, and 3% for miscellaneous uses, including aluminum-base hardeners[7].

Current aluminum scrap separation techniques based on water elutriation, heavy media, and eddy-current technologies produce aluminum concentrates that are mixtures of cast and wrought aluminum alloys and therefore are not suitable for use in wrought alloy production. This is unfortunate since aluminum scrap entering the recycling stream contains steadily increasing amounts of wrought alloys. The wrought fraction of these mixtures has a higher value (3 – 5 cents per pound) when separated[9], and its reuse as wrought alloys would prevent unnecessary downgrading. Furthermore, for most efficient recycling, wrought aluminum alloys require more segregation. This means sorting at least by main groups and preferably by alloy. Bureau technology for mechanically separating wrought and cast aluminum alloys and current research on identification techniques for larger pieces of wrought aluminum scrap are discussed below.

Mechanical processing

Wrought and cast aluminum alloys may be separated because of a difference in mechanical properties in the 520 – 580°C temperature region. Tests using both scrap aluminum and specific alloys demonstrated that there is a well-defined temperature range where casting alloys lose their ductility and become brittle while wrought alloys remain ductile. Samples were heated in an electric furnace and fragmented in a laboratory hammermill. Cast aluminum alloys tested included 208, 319, 360, 380 and 413. Soak times of 20, 40 and 60 min at temperatures of 540, 560 and 580°C were investigated. The tests showed that as the solidus temperatures increase, longer soak times and higher temperatures are necessary for embrittlement. These results are in agreement with published data[10] and support the hypothesis that the mechanism of the reduction of mechanical strength and ductility of the cast alloys is softening or melting of intergranular eutectic regions.

Using aluminum obtained from automobile shredder nonferrous rejects, tests were made to (1) establish if there are any relationships between final product size, soak temperature, and/or soak time at temperature, and (2) determine what level of upgrading can be expected from typical mixed cast and wrought aluminum scrap concentrates. The average distribution of the sample was 30% minus 1 in. and 70% plus 1 in. The minus 1 in. fraction contained almost no wrought alloys. The plus 1 in. fraction contained 66% cast, 30% wrought, and 4% other (mostly combustible); it was therefore used for actual testing. Sample size was about 11 lb. Temperatures of 500 – 580°C in 20°C increments and soak times of 1 – 6 h in 1 h increments were used. The oversize material remaining from the tests at 520 and 540°C was subsequently reprocessed to evaluate the merits of multistage heating, crushing, and screening. The plus 1 in. material from processing at 520°C was reprocessed at 540, 560, 570 and 580°C. Material from the 540°C test was similarly reprocessed at 560°C. The soak time in each case was 1 h. No wrought scrap reported to the minus 1 in. fraction under any of the above conditions.

The cast aluminum product distribution was evaluated as a function of soak time and temperature with respect to two objectives. The first was to find conditions that minimize the quantity of cast aluminum that remains in the plus 1 in. wrought fraction. The second objective was to minimize the quantity of cast aluminum reduced to less than 12 mesh. Remelting

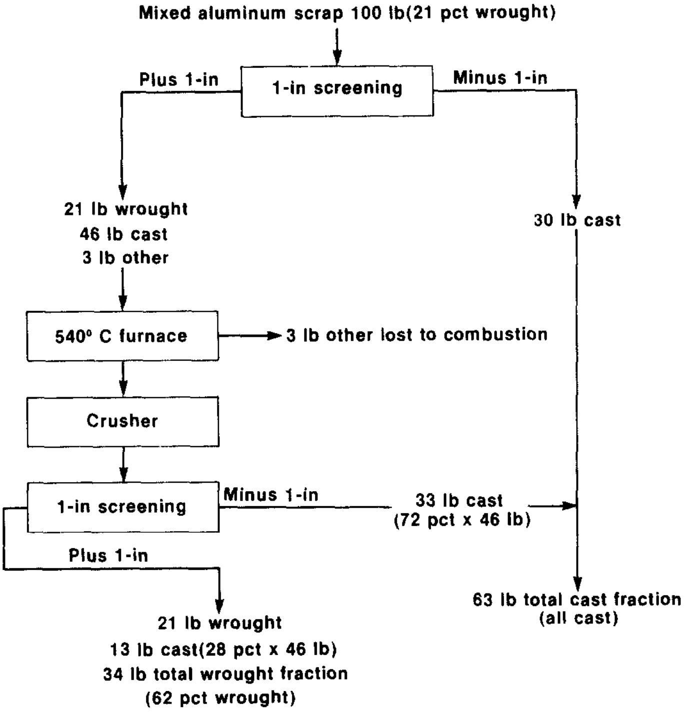

Fig. 1. 540°C hot-crush processing results.

aluminum scrap that is less than 12 mesh increases melting losses, flux requirements, and dross generation rate.

The flowsheet for single-stage processing of mixed aluminum scrap is shown in Fig. 1 for the 540°C furnacing operations. The operating temperature of the furnace is the only variable for this series of tests; other processing steps remain the same. Results of single-stage processing are listed in Table 1. Processing at 500°C yielded limited fragmentation. The average value for cast alloy remaining in the plus 1 in. fraction was 72%. The feed would therefore be expected to be upgraded from 21 lb of wrought metal per 100 lb of mixed alloys (before prescreening) to a wrought product (plus 1 in.) of 21 lb of wrought alloy and 33 lb (72% of 46 lb) of cast alloy (39% wrought).

Results from testing at 520°C indicate that the average mixed feed could be upgraded into a wrought fraction containing 21 lb of wrought alloy and 21 lb of cast alloy (50% wrought).

Processing at 540°C further improved the fragmentation of cast alloys. Cast material at this temperature was very sensitive to external forces and tended to break apart as the crucible contents were being discharged into the hammermill. The wrought product produced at this temperature would contain 21 lb of wrought alloy and 13 lb of cast alloy (62% wrought).

Testing at 560°C resulted in considerable melting of aluminum eutectics for soak times

Table 1. Distribution of cast aluminum alloy after single-stage, hot-crush processing, wt%

Temperature (°C)	Greater than 1 in.	Less than 1 in. plus 12 mesh	Less than 12 mesh
500	72	26	2
520	46	42	12
540	28	57	16
560	12	50	38

greater than 2 h. This temperature appears to be the upper limit for single-stage processing of scrap aluminum. The wrought product would contain 21 lb of wrought alloy and 6 lb of cast alloy (78% wrought). Bulk melting of the sample occurs at 580°C.

Multistage processing results are listed in Table 2. Consider a 560°C final processing temperature. The amount of cast alloy reporting to the wrought fraction (plus 1 in.) was 12% for 560°C single-stage processing, 10% for two-stage processing at 540 and 560°C, and 9% for three-stage processing at 520, 540 and 560°C. This in itself is not a significant improvement over single-stage processing, but the fines generation rate is 38, 23 and 21%, respectively, while the desirable plus 12 mesh, minus 1 in. fraction increases from 50 to 68 to 70%.

Since single-stage processing has an apparent upper temperature limit of 560°C, two additional tests were made at 570 and 580°C to determine if a higher temperature limit is feasible when using multistage processing. The results were favorable, indicating a reduction of the cast alloys remaining in the oversize to 1% of the original cast portion, while the fines fraction was not significantly increased. The best wrought product therefore would be contaminated by only 2% casting alloy. No bulk melting was observed. Typical process products are shown in Fig. 2.

Drop tests, simulating a rotary kiln with internal lifting vanes, were made to investigate the feasibility of using this type of equipment for both heating and crushing. The tests showed that increases in impact energy (height), number of cycles, and soak temperature all resulted in increased fragmentation. Increases in temperature had a much greater influence on fragmentation than did an increase in impact energy, since the higher temperature would result in more liquid metal present relative to the amount of solid phase. This greatly increases breakage. At 545°C and a 2-ft drop height, five heat-drop cycles reduce only 28% of the cast material to less than 1 in. Increasing the drop height to 3 ft results in 60% of the material being

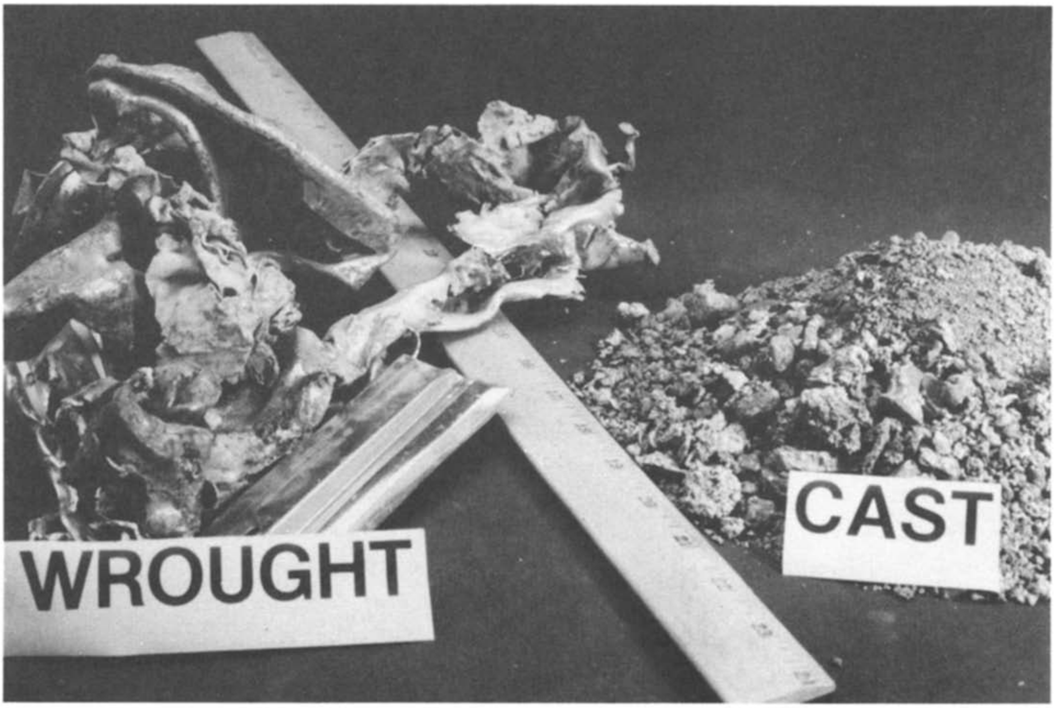

Fig. 2. Typical wrought and cast aluminum products.

Table 2. Distribution of cast aluminum alloy after multi-stage, hot-crush processing, wt%

Temperature (°C)	Greater than 1 in.	Less than 1 in. plus 12 mesh	Less than 12 mesh
520 – 540	15	66	19
520 – 540 – 560	9	70	21
520 – 540 – 560 – 570	4	74	22
520 – 540 – 560 – 570 – 580	1	76	23
540 – 560	10	68	23

reduced to less than 1 in., in five cycles. At 560°C and a 3-ft drop height, all the material is reduced to less than 1 in., after just three cycles.

The mechanical processing tests showed that the more brittle behavior of cast aluminum alloys at elevated temperatures can be used to separate cast and wrought aluminum alloys. Multistage processing appears to yield the best separation and least fines generation.

Identification of wrought aluminum

As new alloys are introduced into various product lines, identification and separation of the various wrought aluminum alloys become both more important and more difficult. A common misconception is that separation of aluminum-base alloys from alloys based on other metals is sufficient for recycling because most of the aluminum alloys are 90 – 95% aluminum. For most efficient recycling, wrought aluminum alloys require the strictest possible segregation, at least by main groups and preferably by alloy. The most important alloying elements to be considered for separation are copper, manganese, and zinc. Alloys based on these elements as primary alloying constituents are classified as 2XXX, 3XXX and 7XXX, respectively. Chemical spot testing and emission spectroscopy are the methods recommended for identification of these alloys[11]. Both require some expertise and are somewhat tedious. The demands for time and talent are not often justified owing to the relatively low price of aluminum alloys.

Current Bureau research indicates that hardness and eddy current measurements are applicable as new methods in aluminum alloy identification. Both techniques can be carried out using small portable devices. The eddy current test is an indirect measurement of the electrical conductivity. In most cases, both hardness and electrical conductivity vary widely between the wrought aluminum alloy groups. The possibility of some overlap is present for both techniques because in both cases the measurement is of only one physical property. Physical properties like hardness, conductivity, strength, etc., are functions not only of alloy composition but also of metallurgical history. Fortunately, it is very common for items of a given aluminum alloy to be heat treated, worked, etc., in the same way as other items of the same alloy. In practice, this means that the physical properties for a given alloy are in a fairly narrow range.

Tests were done using test coupons in the annealed state, "O" temper. A Barber – Coleman hand-held hardness tester* and a Roth "Sortationer" eddy current tester were used for the measurements. Results, along with composition and conductivity data, are given in Table 3. Examination of the data shows that sorting is possible by first using the eddy current tester. Alloys 2024, 3003 and 6061 could then be separated by using the hardness tester.

Samples of as finished 6061 and 6063 alloy products were obtained from a large primary aluminum producer. For 6061, a Barber – Coleman hardness of 95 and an eddy current reading of 7.5 were obtained. Values for 6063 are 83 and 7.3. It is to be expected that the 6061 will be harder than the 6063 in all cases where the temper is similar. The conductivity data indicate that, in general, for higher alloy content, the lower the conductivity, the higher the sortationer

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* Reference to specific equipment does not imply endorsement by the Bureau of Mines.

Table 3. Hardness and eddy current data for some annealed aluminum alloys

Alloy	Composition, wt%					Hardness, Barber-Coleman reading*	Conductivity, (% IACS†)	Eddy current reading*
	Cu	Mn	Mg	Cr	Zn			
1100	0.2	0.05				44–45	59	4.8
2024	4.5	0.6	1.5	0.1	0.25	68–70	50	6.8
3003	0.2	1.3			0.1	55–56	50	6.8
5052	0.1	0.1	2.5	0.25	0.1	71–72	35	7.5
6061	0.3	0.15	1.0	0.25	0.25	59–60	45	6.8
6063	0.1	0.1	0.7	0.1	0.1	ND	58	ND
7075	1.6	0.3	2.5	0.3	5.6	75–76	30	7.0

ND Not determined.
* Arbitrary units.
† International annealed copper standard.

Table 4. Comparison of eddy current results.

Alloy	Roth Sortationer reading*	Hocking Phasec D5 reading*	
		x	*y*
2024	6.8	-0.8,	-0.4
3003	6.8	0.6,	0.2
6061	6.8	-1.0,	-0.4
7075	7.0	-1.4,	-0.4

* Arbitrary units.

reading. This trend can be seen both by comparing the alloy groups and by comparing 6061 to 6063. The feasibility of separating 6061 and 6063 is important because mixtures can be safely recycled only into 6061. Alloy 6063 contaminated with 6061 would have higher strength than expected and could ruin extrusion dies.

The use of a more sophisticated eddy current tester, the Hocking Phasec D5, gives good separation for aluminum alloys indistinguishable using the Roth Sortationer. In simple eddy current instruments, the voltage across the test coil may be used as a measure of the eddy current effect. This signal can be manipulated to produce a meter reading indicative of conductivity. Phase and amplitude variations exist in this response, and one may mask the other in the simple instruments. Improved separation results from the ability to resolve eddy current response into its amplitude and phase components. These responses are shown on the instrument screen as horizontal and vertical coordinates and are listed as x, y coordinates in Table 4.

Results to date indicate that hardness and eddy current testing may be used for wrought alloy identification. Several alloys could be identified reliably using the simple eddy current and hardness tester in combination. The same group of alloys could also be identified using a more complex eddy current tester that reports the individual components of the eddy current. Research is continuing to identify methods that are simple, fast, and less dependent on sample history.

HIGH-VALUE SCRAP

Because the United States is almost totally dependent on imports of the critical metals chromium, cobalt and nickel, attention has been given to the reduction of downgrading and discarding of scrap materials containing these elements. The traditional scrap sorting techniques such as object and color recognition, apparent density, magnetic properties, spark testing, and chemical spot tests[2,11] are often inadequate for sorting the complex materials containing these elements into discrete alloys. Contacts with superalloy recyclers indicate that separation into discrete alloys is ultimately the only acceptable way of recycling these alloys without recovering individual elements through pyrometallurgical or hydrometallurgical processes[12].

Approximately 25 000 tons of superalloy scrap and 140 000 tons of stainless steels are downgraded yearly during recycling[12 – 13]. Scrap identification and segregation are necessary first steps to reduce downgrading. The use of several instrumental techniques, field experience with these techniques, and current research on instrumented spark testing are described below.

Identification techniques

Techniques such as thermoelectric response, emission spectroscopy, and fluorescent X-ray spectrography offer potential to improve the accuracy and ease with which identification can be accomplished. Each of these techniques can be used singly with some success, particularly X-ray spectrography. A combination method that enhances the individual sorting efficiency of the thermoelectric and emission spectroscopy methods has been devised.

The samples used in this study are listed in Table 5. Since all of the techniques used can be interfered with by mill scale and other surface impurities, the surfaces were prepared by wet grinding and degreasing.

A Technicorp model 850/950 WT Alloy-Separator was used to measure the thermoelectric response of the alloys listed in Table 5. Thermoelectric instruments for identification of metals and alloys are based on the Seebeck effect (the principle of thermocouples). The magnitude of the potential difference depends on the temperatures of the two junctions and on their composition. Thus, if an unknown metal forms a junction with a known metal at a known temperature difference, the unknown metal may be identified. However, this potential is sensitive to changes in microstructure and surface conditions due to heat treatment, cold working, etc., as well as compositional differences. The magnitude of this change in potential is small for the alloys used in this study (usually <1%) compared to changes in instrument reading with composition. The system was fairly stable, showing the same small amount of deviation (<2%) in long-term testing as in day-to-day tests.

Table 5. High-value alloys used

Stainless steels	Nickel-base alloys	Iron-base alloys	Cobalt-base alloys
201	Monel 400	Haynes 20 MOD	Haynes 188
301	Monel K500		Haynes 25
303			
304	Inconel 600		
316	Inconel 625		
321	Inconel X-750		
347	Inconel 718		
	Hastelloy B-2		
	Hastelloy S		
	Hastelloy C-276		
	Hastelloy G		
	Nickel 200		
	Nickel 201		
	Nimonic 75		
	Nimonic 80A		
	Nimonic 90		
	Incoloy 800		
	Incoloy 825		

A Clandon Metascope, a small hand-held spectroscope, was used to observe the emission spectra of the alloys. Its wavelength range is 420 – 650 nm; an 80-nm wavelength range can be viewed in the spectroscope at one time. The Metascope can be used in different modes. The simplest is to determine the absence or presence of a given element in the sample by looking for a specific line or lines corresponding to that element. Knowledge of alloy specifications is then used to decide if the sample is a given alloy. Further, this device can be used to quantitatively determine the amount of a given element present in the sample by comparing the intensity of the line in question with its intensity for a standard. The relative amounts of an element present in two samples can be determined in this way without reference to an absolute standard. Finally the alloy can be grouped or specifically identified if the operator has the experience to recognize the spectral patterns corresponding to the various alloys.

Combining the thermoelectric response and optical emission spectroscopy techniques resulted in a relatively simple sorting scheme. The first step is to measure the thermoelectric response. This results in the identification of four fractions, (thermoelectric response readings in parentheses):

1. A 200 – 300 series stainless steel – Incoloy 800 – Haynes 20 MOD fraction (585 – 615).
2. A Monel fraction (340 – 355).
3. A pure nickel fraction (460 – 470).
4. A superalloy fraction (625 – 725).

Using the spectroscope, we can then identify and separate from each other low- or no-molybdenum 18-8 grade stainless steels (301, 303, 304), 316 stainless steel, Haynes 20 MOD, Incoloy 800, and the 200, 321 and 347 stainless steel fractions. The same spectroscopic technique can be applied to the superalloy fraction. This results in the three superalloy fractions of high, medium and low molybdenum content. By reapplying the thermoelectric data, or observing the spectra again, these fractions can be further broken down into alloy classes. For example, the medium molybdenum fraction can be segregated into the individual alloys Inconel 718 and Incoloy 825 on the basis of the thermoelectric readings: 625 for Incoloy 825 and 640 for Inconel 718. The high-molybdenum fraction can be separated into the individual Hastelloy and Inconel components by using thermoelectric readings or further observations of the spectra. The flowsheet in Fig. 3 shows graphically how these separations are completed in two or three steps. A chemical spot testing scheme for the same separation would contain more than twice as many steps.

A Texas Nuclear model 9266 Alloy Analyzer was used to analyze the samples in Table 5. This hand-held energy-dispersive instrument generates X-rays using iron-55 and cadmium-109 radioactive sources and uses a scintillation counter for detection. Alloys with spectral intensities and compositions stored in the instrument memory can be identified by name. Other alloys can be identified by comparing the elemental analysis with alloy chemistry specifications. Intensity-composition data for 66 alloys are stored in the instrument's memory. Seventeen of the 27 alloys in Table 5 are included in the memory of the instrument. The device identified 16 of the 17 by name. The elemental analysis for each superalloy in the array was sufficient so that the correct identification could be made by comparison of X-ray-determined values and alloy specifications. While this mode is relatively tedious, it complements the direct identification mode and makes the instrument successful in separating the entire superalloy group into individual alloys. Details of the identifications are listed in Table 6. Even given the limitations of the X-ray analyzer apparent from an examination of Table 6, it is a very useful device. Identifications of alloys in the memory generally take less than 90 sec, and operation of the instrument is very simple. Sometimes the memory limitation is of no consequence in the real world. For example, the unit successfully indicates special 300 series stainless steels (316, 317,

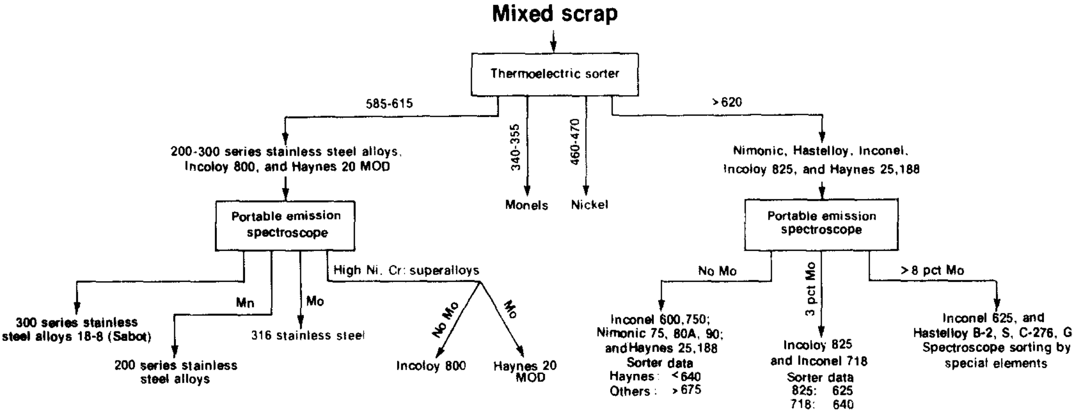

Fig. 3. Instrumental identification technique for sorting stainless steels, nickel alloys, and superalloys; readings in arbitrary units.

Table 6. Fluorescent X-ray spectrographic results

Alloy	Present in memory	Identification
SS 201	"200", set for 202	200 or SS
SS 301	No	SS
SS 303	No	SS
SS 304	Yes	304
SS 316	Yes	316
SS 321	Yes	321
SS 347	Yes	347
Monel 400	Monel	Monel
Monel K500	Monel	Monel
Inconel 600	Yes	Unknown or 600
Inconel 625	Yes	625
Inconel X-750	Yes	X-750
Inconel 718	No	Unknown
Hastelloy B-2	No	B
Hastelloy S	No	Hastelloy C-4
Hastelloy C-276	Yes	C-276
Hastelloy G	Yes	G
Nickel 200	Yes	Ni 200
Nickel 201	No	Ni 200
Nimonic 75	No	600
Nimonic 80A	No	600
Nimonic 90	No	601
Incoloy 800	Yes	800
Incoloy 825	Yes	825
Haynes 20 MOD	No	UHB 904
Haynes 188	Yes	188
Haynes 25	Yes	25

321, 347). Other steels not in memory (301, 303) fit into a commonly marketed stainless steel fraction.

Any of the devices discussed above can be used to better identify high-value scrap. Combining thermoelectric response with optical emission spectroscopy often results in specific alloy identification. However, the X-ray spectrograph in many situations is more convenient than the combination method. The cost of the device is about $23 000. Other X-ray devices having larger memories and semiconductor detectors are available. These instruments offer more flexibility at higher cost. The thermoelectric sorter and optical spectroscope cost about $4 200 and $5 600, respectively.

Field experience

Field tests are in progress at the Cherry Point Defense Property Disposal Office (DPDO), Cherry Point, North Carolina. The purpose is twofold: (1) to provide an economic justification for Defense Department scrapyards to institute or reinstitute segregation of scrap metal before selling it, and (2) to evaluate Bureau of Mines scrap identification procedures using thermoelectric response, optical spectroscopy, and fluorescent X-ray spectrography. The Cherry Point DPDO was selected because its major source of scrap, the Naval Air Rework Facility (NARF), generates large amounts of high-value scrap. The metallic scrap disposed of by NARF includes low-alloy steels, stainless steels, titanium alloys, and various high-nickel and high-cobalt alloys used in helicopters and jet aircraft. At present, the Cherry Point DPDO is marketing these materials as scrap classification listing (SCL) H24 (unsegregated metallic scrap) at a price of approximately $0.4/lb. The DPDO does not have permanent staff to perform separation by alloy.

No problems were encountered in identifying the scrap using the previously described equipment and methods. Of the more than 40 tons of scrap sorted during the initial phase of the test, more than half is high-value scrap. The rest is divided mainly between aluminum, mixed iron and steel, low-alloy steel, and tool steel. The high-value fraction contains about 16 000 lb of nickel, 6 000 lb of chromium, and 1 200 lb of cobalt.

The scrap consists mostly of easily recognizable shapes. Once prototype samples were identified, object recognition was used to sort the material. Thermoelectric response is used to check the quality of sorting. One SCL can contain several similar alloys. For example, SCL TO8 includes five Inconels. Generally, the thermoelectric response is nearly the same for alloys within one SCL but quite different for alloys in other SCLs. Since each measurement requires only a few seconds, this is a very quick way to check a bin or pile of sorted material for misidentified pieces. The check showed that less than 5% of the objects had been misidentified. If the value of the scrap as determined by competitive bids minus the labor costs exceeds the current sales proceeds for unsegregated scrap, the test will be considered a success. Based on past sales, the value of the sorted fractions has ranged from about $0.15/lb for stainless steel to $1.50/lb for Inconel to $7.00/lb for high-cobalt alloys.

Spark testing

Spark testing depends on the observation of the pattern of sparks that results when a metal or metal alloy is ground on an abrasive wheel. Sparks occur because most metals and alloys in the finely divided state oxidize rapidly when heated to incandescence. When metals or alloys are ground using a high-speed grinding wheel, the fine particles torn loose are heated both by the frictional forces of the wheel and by overcoming rupture resistance. As the metal or alloy reaches incandescent temperature, it burns. The resulting pattern of sparks can be used to identify many metals and alloys by examining the spark pattern for shape of spark stream, color, and various characteristics that are imparted by alloying constituents. Results of using the technique are very dependent on the skill and experience of the tester.

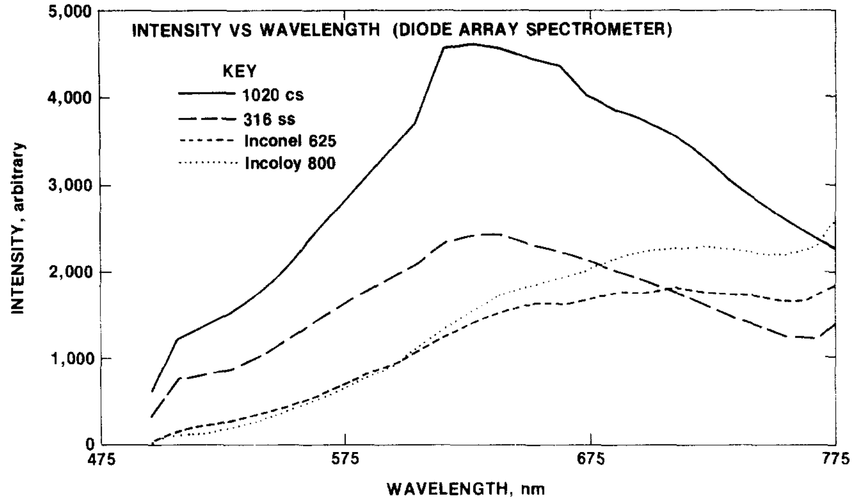

Fig. 4. Spark spectra for several metals showing the effect of increasing nickel content.

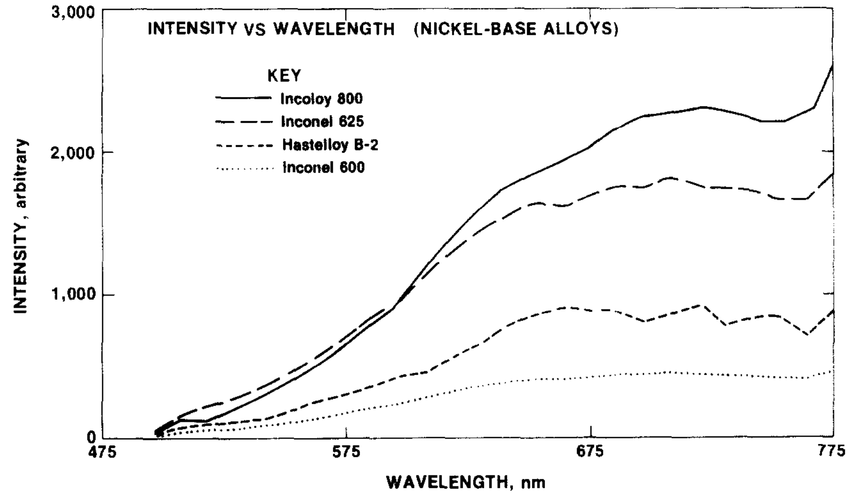

Fig. 5. Spark spectra for some nickel-base alloys.

Bureau researchers are using spectrophotometric methods to take the place of the highly skilled sorter. The spectra presented here were recorded using photodiode array optical spectroscopy. The photodiode array consisted of 1 024 photodiodes on a section of 25-mm silicon chip. The detector was attached to a Jarrel-Ash model 82-482 spectrometer. The detector-spectrometer system is controlled by a Tracor Northern model TN-1710 signal analyzer with a model TN-1710-21 spectrometer module. Data reduction and storage are performed with an LSI-11 microcomputer. Other equipment has been used and is described elsewhere[14].

Figure 4 shows the spectra for a mild steel, a stainless steel, an Inconel, and an Incoloy. A comparison of the individual spectra reveals variations in intensity versus wavelength that are attributable to composition differences. As the amount of alloying is increased from a mild steel to stainless steel to Incoloy and finally to Inconel, a decrease in the maximum intensity and a shift toward the red end of the spectrum are apparent.

Figure 5 shows the spectra for Incoloy 800, Inconel 625, Hastelloy B-2, and Inconel 600. For

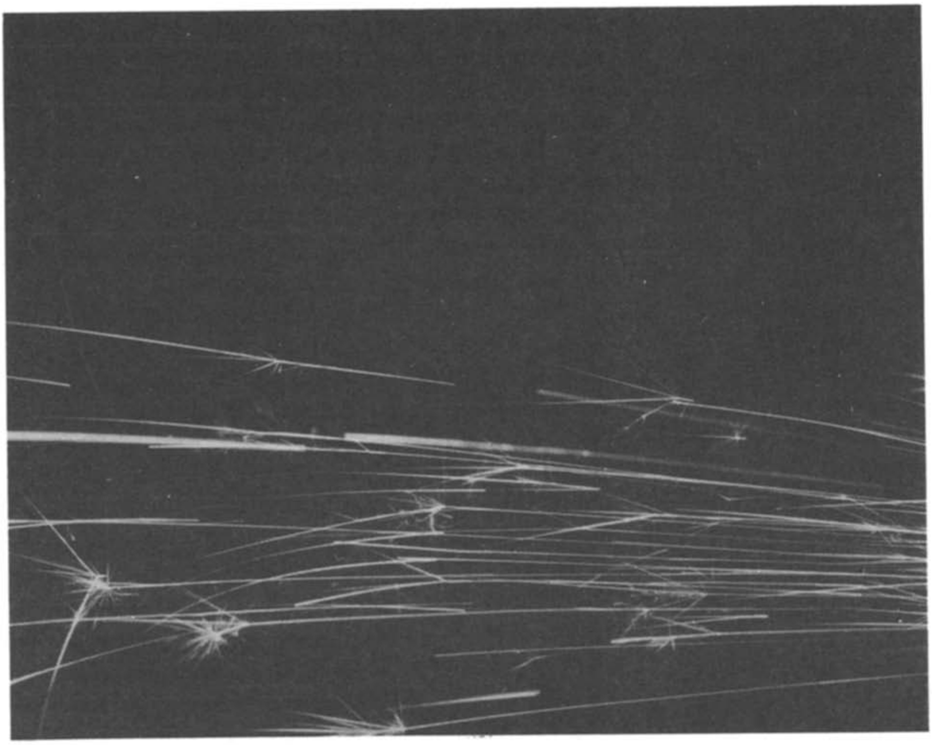

Fig. 6(a). Photograph of 1020 carbon steel spark pattern.

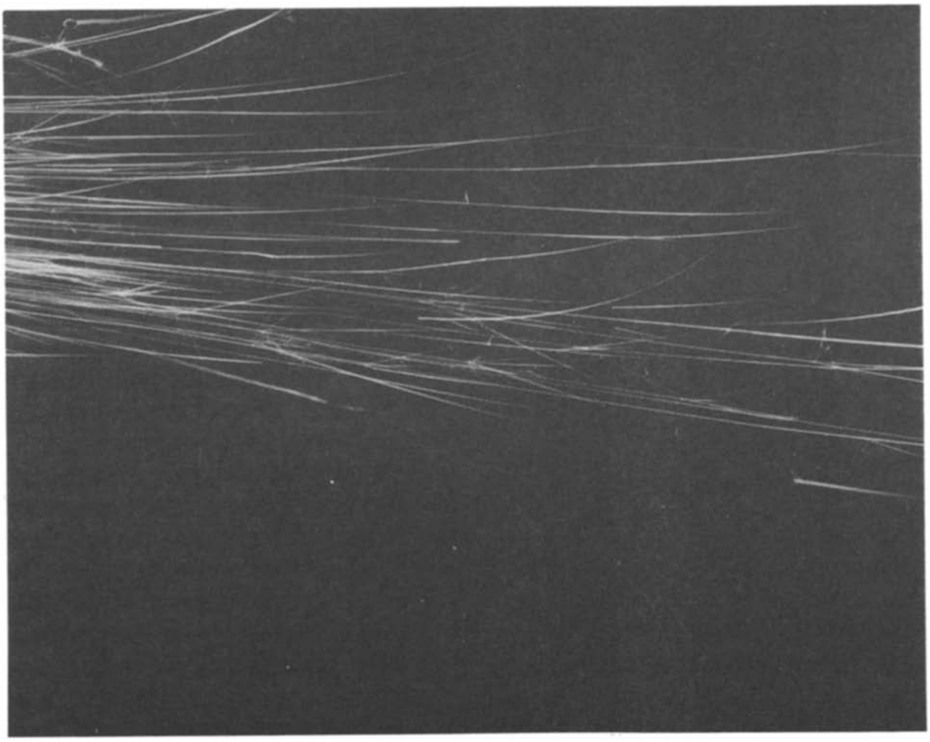

Fig. 6(b). Photograph of 201 stainless steel spark showing the effect of carbide formers on the pattern.

conventional spark testing, the latter three alloys all have "short red sparks." The differences in spectral intensity versus wavelength are clearly evident.

The effect of alloying on the pattern of sparks of steels is a lowering of the temperature, as evidenced by the shift to the cooler red end of the spectrum. Riezler[15] showed that an unalloyed carbon steel (0.10% C) had a spark temperature of 1 640°C and that as the carbon level increased, so did the temperature of the spark (1.00% C = 1 740°C). In steels containing W, Cr and Mo, the spark temperature decreased as the amount of alloying increased. Riezler's measurements agree very well with the data generated in this study. From our work and that of others[16], if the alloying elements have a higher melting point than the iron matrix, then the spark temperature will be lower and the color will be tinted towards red. The degree of change in color tint then depends on the amount of alloying elements. If, however, the alloying element has a lower melting point such as Mn, then the spark pattern will be both brightened and shifted toward the hotter end of the spectrum[17]. Higher melting components cause larger shifts.

Several authors have suggested that the oxidation of carbon to carbon dioxide and possibly carbon monoxide plays a principal role in the spark stream of steels[16–19]. As a particle is heated rapidly, it tends to become spherical, the surface begins to oxidize to iron oxide, and the carbon is oxidized to carbon dioxide. The iron oxide easily flakes off, and iron is rather soft and plastic at the temperatures in a spark stream. Since carbon dioxide occupies an order of magnitude more volume than the original carbon, the gas escapes from the pellet, causing the secondary bursts. It has been suggested[16] that changes in the alloying elements might change the characteristics of the oxide film in such a way as to give the various spark characteristics.

Another explanation may be that many of the alloying elements, e.g. Cr, W, Mo, V and Ti, readily form carbides that are stable at high temperatures so that there is insufficient carbon in the matrix to form cementite (iron carbide). If we compare the spark pictures of 1020 carbon steel (0.2% C) to 201 stainless steel (approximately 0.15% C) in Figure 6 a and b there are very few bursts for the 201 stainless steel. The 201 stainless steel contains 16–18% Cr, which is a strong carbide former. A similar comparison can be made between the spark spectra of 316 (0.08% C) and 316 L (0.03% C) stainless steels. The spectra are identical, again due to the carbon being bound up as chromium and molybdenum carbides. In both of these comparisons, the alloy content masks the effect of changes in carbon content. The rapid heating rate during spark formation does not allow time for existing carbides to dissolve in the gamma iron matrix. This is especially the case in the high- and low-carbon 316 stainless steels where the chromium and molybdenum carbides present do not go readily into solution.

The practical result of the instrumented spark testing research is that the spectroscopic examination of the spark pattern provides a means to identify scrap metals that previously could not be identified by conventional visual spark testing techniques. For example, the presence of a high-nickel alloy is visually indicated by a short red spark. Using conventional techniques, additional testing would be required before identification of a particular nickel-base alloy can be made. Indications are that the new technique will be able to provide specific identification of the high-nickel alloys. Another practical application of this technique would be the separation of 316 stainless steel (2.5% to 3% Mo) from 304 stainless steel, a difficult separation to make using the conventional spark test.

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