This invention relates generally to improved methods of and apparatus for detecting the presence of slag in rolled sheet metals such as steel, for example, and more particularly to such methods and apparatus which may be employed concurrently with one of the rolling operations or the like to which the sheet is subjected.

In the preparation of rolled sheet metal a billet of the metal is first obtained, generally by pouring the molten metal into a suitable mold. Where the molten metal batch includes slag or other impurities which differ in specific gravity from the desired metal, the solidified billet will exhibit a core. Steel is one of the more common metals having this characteristic core which contains slag inclusion. In hot rolling of a steel billet into a long sheet, the slag inclusion is rolled out with the billet and does not separate at the boundary between slag and slag-free metal. In subsequent cold rolling, however, the passage of a portion of the sheet metal containing the slag inclusion through the rolling process causes the sheet to tear and fracture along the slag boundary.

In order to prevent the damage to the rolling equipment which results upon the occurrence of a slag tear in a sheet which is being cold rolled, it is necessary to sever and discard the portion of the billet or hot rolled sheet containing the slag. Heretofore the location of the exact point at which to sever the hot rolled sheet could not be readily determined and the actual cut was made at a point which allowed a considerable margin of error. This procedure results in a continuous waste of a substantial amount of the slag-free sheet and introduces an element of uncertainty in that slag inclusions may extend beyond the point of severance. The damage resulting from an attempt to cold roll a sheet containing a slag inclusion necessitates expensive repairs to the equipment and a loss of valuable production time.

It is an object of this invention to provide improved method and means for detecting slag inclusion in rolling sheet stock.

Another object is to provide method and means for accurately determining the longitudinal position in a rolled sheet of a discontinuity boundary.

A further object is to provide for the detection of the boundary between two portions of a sheet with the aid of a trace element present in the material of one of the portions.

Another object is to provide slag detection in a continuous process sheet and include means responsive to the slag detection for indicating or severing the sheet at the slag boundary.

These and other objects will appear as the invention is more fully understood. One arrangement of the invention provides for a continuous relative motion between the sheet material to be examined and a detection apparatus capable of sensing the presence of an element characteristic of the material on one side of the boundary to be detected. The detection apparatus is arranged to be selectively responsive to the wavelength of fluorescent X-rays excited from the characteristic element to provide rapid and certain determination of the boundary of the area containing the element.

In the drawings:
Fig. 1 is a plan view of a sheet having a slag inclusion; Fig. 2 is an elevational view of one form of the invention; Fig. 3 is a plan view of a modification employing a plurality of detectors; Fig. 4 is a plan view of an arrangement for element detection on a stationary sheet; Fig. 5 is an elevational view of a modification using an alternative detector; and Fig. 6 is a chart for describing a feature of the invention; and Fig. 7 is a fragmentary view of an apparatus similar to that shown in Fig. 5 but having a scintillation counter type detector.

In Fig. 1 a representative sheet of material 11 such as hot rolled sheet steel which is to be examined for a slag inclusion 12 is shown. The slag inclusion 12 is drawn with the sheet 11 during the hot rolling process in a manner which forms an indeterminate boundary 13 between the slag-free sheet 11 and the portion which includes the slag 12. At some longitudinal position 14 of the sheet 11 the slag inclusion terminates and this position 14 may be satisfactorily defined for many purposes by a transverse axis A-A. In other applications it may be desirable to locate the actual limits defined by the boundary 13-13 which, it will be understood, does not necessarily exhibit a visible manifestation.

This invention provides for the location of the boundary 13-13 or the point 14 corresponding to the axis A-A by subjecting the sheet to be inspected to an element detecting process which is adjusted to detect an element which is present in the slag 12 but is not present in the steel sheet 11 or vice versa. In certain applications the invention contemplates the detection of the quantitative change at the boundary 13 of the same element which appears in the portions 11, 12 in different concentrations.

The later method can be practiced by those skilled in the art pertaining to the metal being analyzed by detecting the presence of an element which is contained in the slag 12 and the slag-free sheet 11 in sensibly different percentages and noting the change in magnitude of responses on opposite sides of the boundary 13. In the hot rolling of certain manganese steels, for example, the concentration of manganese in the slag 12 is approximately six percent (6%) while that of the sheet 11 is one-half percent (½%). This difference provides a wide margin for the selective adjustment of magnitude response of the apparatus to be hereinafter described.

An important feature of this invention which may be employed, for example, when the previously described method is not used provides the addition of a trace element in a molten batch which is to be poured into billets. The trace element preferably is chosen as one which follows the chemistry of the slag present in the molten batch and not the chemistry of the batch metal. The added trace element, therefore, is present in the slag inclusion 12 when the billet is rolled into a sheet but is not present in the sheet 11. The extent of the slag inclusion 12 can thus be determined using a detector adjusted to be responsive to the trace element. As an example of this process a small percentage of an alkaline earth, such as barium, or rare earth element such as cerium can be added to a molten batch of steel and will be present in the slag as a trace element while not appearing in the steel itself. By detecting the presence of the trace element in the rolled sheet the slag boundary 13-13 can be determined.

It will be understood that the preceding examples of detecting a change in concentration of an element and
detecting the presence or absence of a trace element are exemplary only and the invention is not to be considered as limited thereto. The elements which appear in different concentrations in any particularly slag and slag-free metal mixture are well known in the metallurgical art and can be readily selected by inspection of the quantitative analysis records which are obtained for all such manufactures. Likewise the choice can be made, by one skilled in the art, of a trace element for addition to a particular molten batch which will combine with the slag but not the batch metal. The slag therefore will be identifiable by the presence of the trace element and the characteristics of the batch metal will be unaltered by the addition of the trace element to the molten batch.

In Fig. 2 an arrangement for practicing the invention is shown in which a steel sheet 15 is passed through successive rolling stages 16 of a conventional hot rolling mill. At any suitable location a detector panel 17 is positioned to examine the moving sheet 15. The detector panel 17 has an X-ray tube 18 supported thereon and encased in a radiation shield 19. The shield 19 has an aperture 21 which is arranged to direct X-ray radiation from the tube 18 upon the moving sheet 15 at any convenient angle, such as 45°. The tube 18 may have a target 22 of molybdenum or copper for the analysis of steel and is suitably energized from a direct power supply 23. The power supply 23 may apply a voltage between 10 and 50 kilovolts and need not be mounted on the detector panel 17, as shown.

The X-ray radiation falling on the sheet 15 excites fluorescent X-rays in the elements therein causing the radiation of a spectrum characteristic of the fluorescing elements. This radiation passes through a collimator 24 which may comprise a plurality of parallel sheets of nickel foil spaced about 0.5 millimeter apart. The narrow beam emerging from the collimator 24 is incident upon a crystal 25 which is supported in a mount 26. The holder 26 supports the crystal 25 for rotation to provide a selective angle of incidence of the collimated beam on the surface of the crystal 25. Also mounted for rotation about the same axis is a radiation shield housing 27 having an aperture 28 and containing a Geiger-Mueller detector tube 29. The tube 29 is in circuit with suitable power supply, counter and indicator circuits 31 which are well known for responding to the level of energization of the Geiger-Mueller tube.

As is known in the art of analyzing samples with fluorescent X-rays, the beam incident upon the crystal 25 is reflected thereby to provide components of the beam at various angles to the normal determined by their respective frequencies because of the diffraction of the beam occurring in the crystal. By means of the rotative adjustment for the crystal 25 and the detector tube 29 the monochromatic component corresponding to any angle may be selected and directed toward the detector 29. The frequency of the given element will be known and the apparatus can be adjusted to detect only that frequency whereupon the response obtained in the counter circuit 31 will be proportional to the concentration of the selected element in the portion of the sheet 15 beneath the beam emanating from the X-ray tube 18.

If desired, the counting rate of the circuit 31 can be recorded with respect to the length of the sheet 15 passing the detector panel 17 by means of a recorder 30. With the crystal 25 and tube 27 set at angles to detect one of the elements present in different concentrations in the two portions 11, 12 of the sheet 15 or to detect a trace element absent in one of the portions 11, 12 as hereinbefore described, the location of the slab termination 14 will be recorded. The sheet 15 can be subsequently severed along axis A—A as determined from the recording. For inclusions 12 of the type illustrated in Fig. 3 it is preferable to locate the detector panel 17 centrally of the transverse dimension of the sheet 15. In the event that the location of the boundaries 13—13 is desired, a more detailed analysis could be made, as shown in Fig. 3 for example, using a battery of independent analyzers 17 extending transversely across the sheet 15. Also, if desired, means can be made responsive to a predetermined counting rate of the circuit 31 to automatically mark or sever the sheet 15 at the axis A—A as will be described.

In the event that analysis of a stationary sheet is desired, the arrangement of Fig. 4 can be used to locate the slag boundary. With this method during the processing or storage of the sheet 15 some period is selected when the sheet 15 is relatively at rest. At this station the sheet 15 is subjected to a battery of independent analyzers 17 disposed longitudinally of the sheet 15. Simultaneous readings of the presence of slag element indicated by the analyzers 17 while the sheet 15 and analyzers 17 are relatively stationary will permit determination of the longitudinal position where the slag disappears.

In Fig. 5 a modification of the invention is arranged on a panel 32 with respect to the rolling sheet 15 similar to the arrangement of Fig. 2. The sheet 15 also receives energy from an X-ray source 33. The fluorescent X-ray emanating from the energized portion of the sheet 15 is received by a radiation detector 34 either directly or through a suitable filter 35. Circuits 36 are provided which respond to the detection of predetermined X-ray frequencies by the detector 34. To prevent the detector 34 from detecting energy directly from the source 33 a suitable shielding 37 may be required. The presence of a given element in the sheet 15 as hereinbefore described produces a response in the circuit 36 which may be utilized to activate a relay 38. The relay 38 may control any desired apparatus 39 such as a marking mechanism or a power shearing machine.

Referring again to the detector 34 and circuits 36, any of the arrangements which are frequency selective to X-ray radiation can be used. For example, any X-ray responsive tube 34 can be used if the absorption filter 35 is used to block almost all radiation other than the wavelength of the element to be detected from energizing the tube 34. The absorption filter 35 can be in the form of a thin film of metal having an absorption edge (i.e. maximum absorption) adjacent the wavelength of the element to be detected. This filtering action is shown in Fig. 6 where the response curve 41 of a thin chromium film is plotted together with a typical response curve obtained from irradiating a steel which contains manganese. As can be seen the manganese response peak 42 falls in a region of low absorption while the iron response peak 43 is greatly attenuated. For manganese present in both slag 12 and steel sheet 11 the circuits 36 can be arranged to be amplitude selective to the increased response of the tube 34 to the higher concentrations of manganese.

Another form for the detector 34 which permits the filter 35 to be eliminated or may be used in conjunction with it if desired, is the proportional counter. Proportional counting is utilized to resolve frequencies of the X-ray spectrum by selective response to the pulse amplitudes obtained as a result of the incident radiation. It has been shown that the amplitude response of a proportional counter varies in accordance with the energy of the radiation quantum which enters the tube. This energy in turn varies with the element being irradiated and thus the amplitude of the pulse output is a measure of the element present in the sheet 15. By adjusting the circuit 36 to bias tube 34 for selective response to pulses of predetermined amplitude, slag detection may be accomplished on the basis of the presence of the element corresponding to that amplitude. It will be understood, of course, that in addition to biasing the circuits 36 for tube 34, the circuits 36 include counter circuits for determining the rate of the selected pulses and controlling the indication or actuation desired in accordance
therewith. Other detectors which produce pulse amplitude responses in accordance with the wavelength of the detected radiation can be used with suitable amplitude selection and pulse counting techniques. An example of such a detector, shown in Fig. 7, which is especially useful at shorter wavelengths is the scintillation counter 34 comprised of a phosphor plate 42 and a photomultiplier 46 and counter and power supply circuits 36.

The methods and apparatus herein disclosed may be readily applied to the practice of the invention by those skilled in the art for all materials exhibiting the requisite properties. These applications as well as the equivalent of the methods and apparatus of the present preferred embodiments are to be considered as within the scope of the appended claims.

I claim:

1. The method of locating the extent of a slag inclusion in a rolled sheet of metal alloy comprising the steps of determining in the slag and slag-free alloy the presence of sensibly different concentrations of one or more elements, selecting one of said elements suitable for fluorescent X-ray analysis, subjecting successive elemental areas of said sheet to fluorescent X-ray analysis of the presence of said selected element, detecting the change in response corresponding to said change in concentration, and utilizing the detected change in response for locating the extent of said slag inclusion.

2. The method of locating the extent of a slag inclusion in a rolled sheet of manganese steel comprising the steps of determining in the slag and slag-free steel the presence of sensibly different concentrations of manganese, subjecting successive elemental areas of said sheet to fluorescent X-ray analysis of the presence of manganese, detecting the change in response corresponding to said change in concentration and utilizing the detected change in response for locating the extent of said slag inclusion.

3. The method of locating the extent of a slag inclusion in a rolled sheet of metal alloy comprising the steps of adding to the molten bath of said alloy a trace element which combines with the slag but does not combine with or deleteriously affect said alloy, pouring said molten batch into billets having slag inclusion, rolling said billets into sheets, subjecting said sheet to fluorescent X-ray analysis for said trace element, detecting the presence of said trace element and utilizing the detection of said trace element for locating the extent of said slag inclusion.

4. The method of locating the extent of a slag inclusion in a rolled sheet of steel comprising the steps of adding to the molten bath of said steel a trace element selected from the group consisting of the alkaline earths, pouring said molten batch into billets having slag inclusion, rolling said billets into sheets, subjecting said sheet to fluorescent X-ray analysis for said trace element, detecting the presence of said trace element, and utilizing the detection of said trace element for locating the extent of said slag inclusion.

5. The method of locating the extent of a slag inclusion in a rolled sheet of steel comprising the steps of adding to the molten batch of said steel a trace element selected from the group consisting of the rare earths, pouring said molten batch into billets having slag inclusion, rolling said billets into sheets, subjecting said sheet to fluorescent X-ray analysis for said trace element, detecting the presence of said trace element, and utilizing the detection of said trace element for locating the extent of said slag inclusion.

6. The method of locating the boundary of a slag inclusion in rolled sheet steel comprising the steps of transporting said sheet at a substantially uniform speed along the direction of rolling, irradiating said moving sheet with a local wavelength of wavelength which excites the fluorescent X-ray spectrum of a predetermined element present in different concentrations in the slag and slag-free sheet, selectively detecting fluorescent X-rays from said element, and utilizing the response of said detection for indicating the position on said sheet of a predetermined change in said concentrations.

7. The method according to claim 6 in which the step of detecting the fluorescent X-rays includes the steps of monochromatizing said fluorescent X-rays by reflecting from a crystal surface and adjusting a radiation detector to receive reflections from said surface at an angle determined by said element to be detected.

8. The method according to claim 6 in which the step of detecting the fluorescent X-rays includes the steps of filtering said fluorescent X-rays to increase the magnitude of the wavelength component of said element relative to other wavelengths and detecting said filtered X-rays with amplitude selection in accordance with said element to be detected.

9. The method according to claim 6 in which the step of detecting the fluorescent X-rays includes applying said fluorescent X-rays to a proportional counter and biasing said proportional counter for response to a predetermined wavelength characteristic of said element.

10. The method according to claim 6 in which the step of detecting the fluorescent X-rays includes the step of selecting the wavelength component of said element with a scintillation counter.

11. Apparatus for detecting the inclusion of slag in a sheet of material, said slag and slag-free material being characterized by different concentrations of a predetermined element, comprising means for irradiating an elemental area of said sheet with a beam of X-rays of a wavelength which excites the fluorescent X-ray spectrum of said element, means for moving said sheet past said area with substantially uniform speed, means for selectively detecting fluorescent X-rays of wavelength characteristic of said element and utilizing means responsive to the detection of the change of concentration of said element.

12. Apparatus according to claim 11 in which said utilization means includes means for recording the detected concentrations of said element as a function of position along the direction of travel of said sheet.

13. Apparatus according to claim 11 in which said utilization means includes means responsive to the detection of a predetermined concentration of said element for marking on said sheet the boundary of said predetermined concentration.

14. Apparatus according to claim 11 in which said utilization means includes means responsive to the detection of a predetermined concentration of said element for severing said sheet substantially at the boundary of said predetermined concentration.

15. Apparatus for detecting the inclusion of slag in a sheet of material, said slag and slag-free material being characterized by different concentrations of a predetermined element, comprising means for irradiating an elemental area of said sheet with a beam of X-rays of a wavelength which excites the fluorescent X-ray spectrum of said element, means for moving said sheet past said area with substantially uniform speed, a plurality of detectors arranged transversely of said sheet adjacent said area for selectively detecting fluorescent X-rays of wavelength characteristic of said element, and means responsive to the detection by each of said detectors of the change of concentration of said element.

16. Apparatus for detecting the inclusion of slag in a sheet of material, said slag and slag-free material being characterized by different concentrations of a predetermined element, comprising a plurality of analyzers arranged in spaced positions longitudinally of said sheet, each of said analyzers including means for irradiating an elemental area of said sheet with a beam of X-rays of a wavelength which excites the fluorescent X-ray spectrum of said element, means for selectively detecting fluorescent X-rays of wavelength characteristic of said ele-
17. The method of locating the extent of a slag inclusion in a sheet of metal alloy comprising the steps of determining in the slag and slag-free alloy the presence of sensibly different concentrations of the same element, selecting one of said elements suitable for fluorescent X-ray analysis, subjecting longitudinally spaced elemental areas of said sheet to fluorescent X-ray analysis of the presence of said selected element, detecting the respective response corresponding to the concentration of said element at said areas, and utilizing said detected responses for locating the extent of said slag inclusion.

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