A MAGNETIC BALANCE FOR THE INSPECTION OF AUSTENITIC STEEL

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ABSTRACT

The paper describes an experimental model of a magnetic balance for measuring the attractive force between a permanent magnet and a specimen of austenitic steel with which it is in contact. Experiments with this model indicate that such an instrument should be of considerable practical value for the inspection of corrosion-resistant austenitic steel in view of the fact that the magnetic permeability has been found to be a good index of the resistance to corrosion of this type of material. The instrument is portable and can be applied to different parts of a completed structure.

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I. INTRODUCTION

In austenitic steel the iron exists in the nonmagnetic or gamma phase. In plain carbon steels this phase is stable only at high temperatures, but it can be retained at ordinary temperatures when the iron is alloyed with proper proportions of certain other elements. Chromium and nickel are among the most important of these elements. In recent years some types of austenitic steel have come into extensive use, primarily on account of their property of corrosion resistance. As corrosion tests are usually tedious and time consuming, and yield results which are frequently difficult to interpret with certainty, efforts have been made to discover whether or not some other more easily determined property can be used as an index of the resistance to corrosion. The property which appears to give the greatest promise for this purpose is the magnetic permeability. In addition to serving as an index of corrosion resistance, the permeability is of importance in cases where the material is to be used in proximity to a magnetic compass.

It is a simple matter to determine the magnetic permeability by well-known ballistic methods when specimens of the material can be prepared in suitable form. These methods are obviously unsuited, however, to the testing of various parts of a completed structure in place. The desirability of such tests arises from the fact that the austenitic structure may be partially decomposed as a result of the treatment applied in the process of construction. Decomposition of the austenite may be brought about also by severe service conditions,
such as high temperature and by mechanical working during fabrication. As a result of the breakdown of the austenitic structure the alpha or more familiar phase of iron forms resulting in reduced resistance to corrosion and an increase in magnetic permeability.

The practical value of a portable instrument for inspecting the various parts of a completed structure of austenitic steel in terms of magnetic permeability was first brought to the attention of the writer by P. E. McKinney, metallurgical engineer of the Bethlehem Steel Co. It was at his suggestion that the development of such an instrument was undertaken.

A consideration of several possible types of measurement, together with the results of preliminary experiments, led to the conclusion that the most promising method was by a measurement of the force of attraction between the specimen and a permanent magnet in contact with its surface. In order to try out this method, an experimental instrument was designed and constructed. In view of the satisfactory performance of this instrument, it is described below in the belief that such an instrument with only minor modifications can be used to advantage for the inspection of austenitic corrosion-resistant steel.

II. DESCRIPTION OF THE INSTRUMENT

Figure 1 is a photograph of the instrument. An astatic pair of magnets is clamped in a pivoted holder carried in jewel bearings. The motion of this pivoted system is limited by an adjustable stop. The lower end of the magnet which comes in contact with the specimen is ground to a hemispherical form to facilitate good reproducibility. The force of attraction between the magnet and the specimen is measured in terms of the torque of a helical spring of phosphor bronze. One end of this spring is clamped to the pivoted mounting and the other to a spindle coaxial with the pivots. The torque is measured by means of a graduated dial which indicates the angle through which the spring is twisted.

Although the actual dimensions of the various component parts are of relatively minor importance, there are certain conditions which must be fulfilled if satisfactory performance is to be obtained. The magnetic element must be astatic, the center of gravity of the moving system must be on the axis of rotation, and the friction in the bearings must be small.

If a single magnet were to be used the torque due to the reaction of the earth's field on the magnet would introduce an error in the readings. This error would vary in magnitude with the orientation of the magnet with respect to the direction of the earth's field. In order to obviate this error, two magnets of equal strength are used. They are inserted in the holder with like poles together so that the resultant torque, due to the earth's field, is zero. The magnets employed in the experimental instrument are of cobalt magnet steel, 5 cm long and 5 mm in diameter.

Since the instrument is intended to be used in other positions than with the base horizontal, there should be no torque due to gravity. In the present instrument this condition is not exactly met. The center of gravity is slightly below the axis of rotation when the base is horizontal. This gives a difference between readings obtained on the same specimen when the base is horizontal and when it is vertical.
Figure 1.—Experimental magnetic balance
This discrepancy could be obviated by providing suitable means for mechanistically balancing the system.

The requirement as to pivot friction is obvious. In an attempt to make the instrument as rugged as possible, the bearings were first made of hardened steel. The friction in these bearings was excessive, being augmented by magnetic attraction due to proximity to the strong poles of the magnets. The substitution of phosphor bronze did not remedy the trouble and finally sapphire bearings and steel pivots were put in. This eliminated excessive friction, but resulted in a somewhat less rugged instrument.

The particular form of spring used was chosen on account of the ease with which variations in strength can be obtained. Several springs were made using different sizes of wire, diameter of coil, and winding pitch. A more compact instrument would result from the use of a flat spiral spring but, for the present purpose, the form employed proved to be very satisfactory.

The dial is 4 cm in diameter and has 100 scale divisions. It is held in position on its shaft by a friction washer which facilitates the adjustment of the zero.

In use, the instrument is placed with its base flat upon the specimen so that the lower end of the magnet comes in contact. The spring is then twisted until the torque is just sufficient to pull the magnet away from the specimen. The torque required is measured in terms of the angle through which the spring is twisted as indicated by the dial reading. The springs used with the present instrument have torque constants ranging from 0.45 g-cm per division to 2.6 g-cm per division. Obviously care must be taken to avoid injury to the pivots and jewels, but with reasonably careful handling such an instrument should be sufficiently rugged for practical use.

III. EXPERIMENTAL RESULTS

In order to investigate the relationship between the readings of the instrument and the magnetic properties of the material, a series of 31 specimens of corrosion-resistant steel was selected from a large number of samples of unknown source and composition which had previously been submitted for test. The maximum permeability of these specimens as determined by the ballistic method ranged from less than 1.01 to 5.31, usually occurring at a magnetizing force of 200 oersteds (gilberts per centimeter). Preliminary tests with the magnetic balance showed a fairly definite relation between the balance readings and maximum permeability, but the discrepancies were sufficiently large and numerous to call for more detailed investigation. Two points were of particular interest, namely, the value of magnetizing force applied to the material under test and the effect of previous magnetic treatment on the results. In the course of the experiments the degree of homogeneity of the material was also found to be an important factor.

The question of the applied magnetizing force was attacked in two different ways, neither one of which gave an entirely satisfactory answer. In an attempt to determine the value of the magnetizing force directly, the total flux emanating from the hemispherical end of the permanent magnet was measured by means of a test coil and ballistic galvanometer. The average flux density was then calcu-
lated by dividing the total flux by the area of the surface of the hemisphere. The magnetizing force thus determined was approximately 900 oersteds. Since the magnetizing force did not exceed 300 oersteds in the previous ballistic tests, new determinations were made at higher magnetizing forces up to 1,000 oersteds. A comparison of the balance readings with the values of permeability at a magnetizing force of 900 oersteds revealed discrepancies fully as great as the comparison with the values of maximum permeability.

The second way in which an attempt was made to find out the effective value of magnetizing force applied by the balance consisted in plotting the balance readings against the permeability corresponding to various values of magnetizing force as determined ballistically. In no case was a better correlation found than that between the balance readings and the values of maximum permeability. These results should probably be expected since the force of attraction is a function not only of the magnetization of the specimen at the point of contact, but also of the magnetization in the immediate vicinity. The different elements of the volume of the material involved would, of course, be subjected to the influence of magnetizing forces of different magnitudes, and the observed mechanical force would be the integrated effect of the whole volume involved. For this reason, it is not proper to consider that the balance actually measures the permeability corresponding to any single value of magnetizing force.

The ballistic tests brought out the fact that the materials varied not only with regard to maximum permeability, but also in the relation between permeability and magnetizing force. This is illustrated by Figure 2 in which curves for samples Nos. 16 and 18 are shown. Although the permeability of the two materials is nearly the

![Figure 2. Permeability curves for two specimens of austenitic steel](image)
same at a magnetizing force of 200 oersteds, it is obvious that they are magnetically quite different. The balance readings for these two specimens were 22.0 and 18.5, respectively.

In the course of the experiments, it was found that the readings obtained were in many cases affected to an appreciable extent by previous magnetic treatment. The reading at a given point, for example, might be changed by several divisions by rubbing the magnet of the balance over the surface of the specimen near the point at which the measurement was made. The effect is most noticeable for the materials of higher permeability. However, if the specimens are demagnetized before a reading and care is taken to avoid rubbing the balance magnet over the surface when placing it in position, readings can be repeated within half a division. Passing one pole of a small electromagnet energized with alternating current over the specimen effectively removes the effect of previous magnetization.

Differences in the degree to which various specimens are affected by previous magnetization are easily explained by the different amounts of magnetic hysteresis exhibited. Observations of coercive force taken from a maximum magnetizing force of 1,000 oersteds gave values ranging from 43 to 178 oersteds. There was no relationship between the coercive force and permeability. The differences in magnetic characteristics would seem to indicate that the materials differ not only in the amount of ferromagnetic material present, but also in its distribution within the structure. The relationships involved might quite profitably be made the subject of further investigation.

Another factor which must be taken into consideration is the degree of uniformity of the specimens. In several cases it was found that, even when care was taken to eliminate the effect of previous magnetic history, readings taken at various points on the surface of the specimen showed differences considerably in excess of the allowable experimental error. Although this introduces an additional difficulty in connection with the calibration of the instrument, the ability to reveal such variations in the material is an important feature.

IV. INTERPRETATION OF RESULTS

Figure 3 shows the relation between the readings of the magnetic balance and the permeability as determined by the ballistic method at a magnetizing force of 200 oersteds. Although there is evidently a very good correlation, especially for the lower values of permeability, it should be borne in mind that the balance actually measures nothing but the mechanical force of attraction between the magnet and the specimen. This force is an integrated effect involving a considerable range of magnetizing force. Since the actual scale readings are functions not only of the magnetic properties of the specimens, but also of the strength of the magnet and of the spring, each individual instrument will have a calibration constant which must be determined by taking readings on a series of specimens whose magnetic properties are known. In many cases, it will be necessary to determine only a certain critical scale reading as the upper limit for satisfactory material. For routine inspection an instrument with a fixed spring tension might prove most satisfactory. For other applications, it would be better to have the dial, so that quantitative values of the attractive force could be obtained.
In the light of the results obtained with the experimental model it seems reasonable to conclude that an instrument of this type would be of considerable practical value for the investigation and testing of austenitic corrosion-resistant steels and other materials having the same range of values of permeability.

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