Low-Cost, High-Speed Domain Refinement without Damage to Insulative Coatings

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Rolling large-diameter hardened steel balls over the surface of high-permeability grain-oriented electrical steel allows lines of plastic deformation to be laid down. Choice of proper Young's modulus and ball diameter enables artificial grain boundaries to be created, producing appropriate domain refinement and loss reduction.

Keywords

ball unit, domains, etch pit, power loss, refinement

1. Introduction

INCREASING the perfection of orientation of grain-oriented electrical steels inevitably increases the grain size of the steel, because only the most perfectly oriented nuclei are allowed to grow. The more perfect the allowed nuclei are required to be, the fewer exist in a given population. These grow at the expense of others, leading to a large grain size.

It is well known that the larger the grain size, the wider the domain wall spacing (Ref 1). Wider domain wall spacing leads to higher mean domain wall velocity for a given rate of flux reversal. Higher domain wall velocity produces greater micro-eddy current losses as the walls move, and overall power loss is increased. Thus, refinement of domain wall spacing is desirable in order to reduce mean wall velocity.

Figure 1 reviews some of the methods that have been used to produce domain refinement by creation of "artificial" grain boundaries. These methods are described in Ref 2 to 4.

2. New Technique for Domain Refinement

2.1 *General*

All domain-refinement methods present disadvantages. Various compromises must be made in terms of cost, speed of operation, heat proofness, engineering complexity, and so on.

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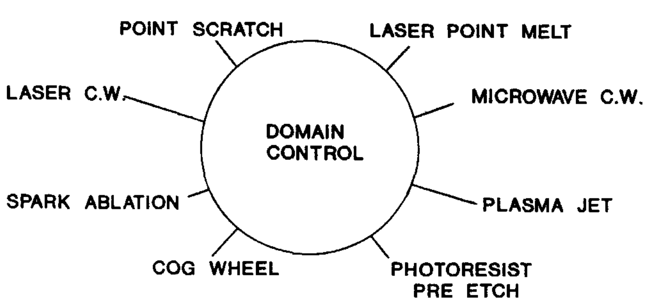

Fig. 1 Methods of domain control

The ball treatment method described in this paper has the advantages of rapid action and low cost. It can be incorporated

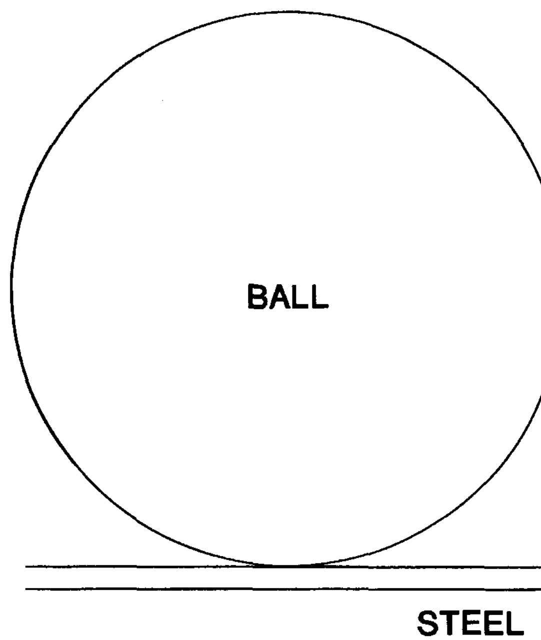

Fig. 2 Contact between ball and steel surface

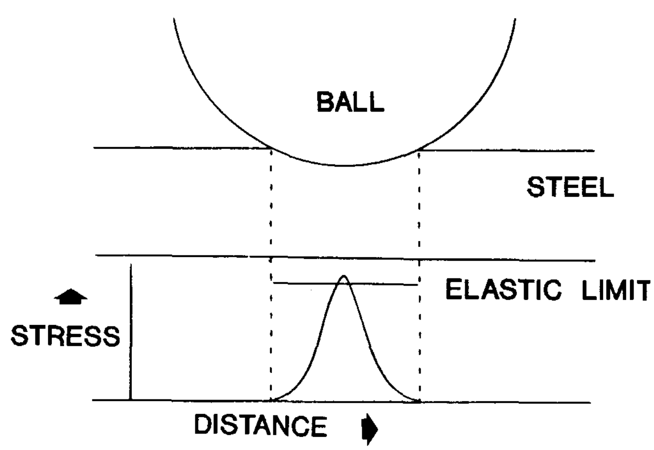

Fig. 3 Relationship between stress and distance across impressed stripe

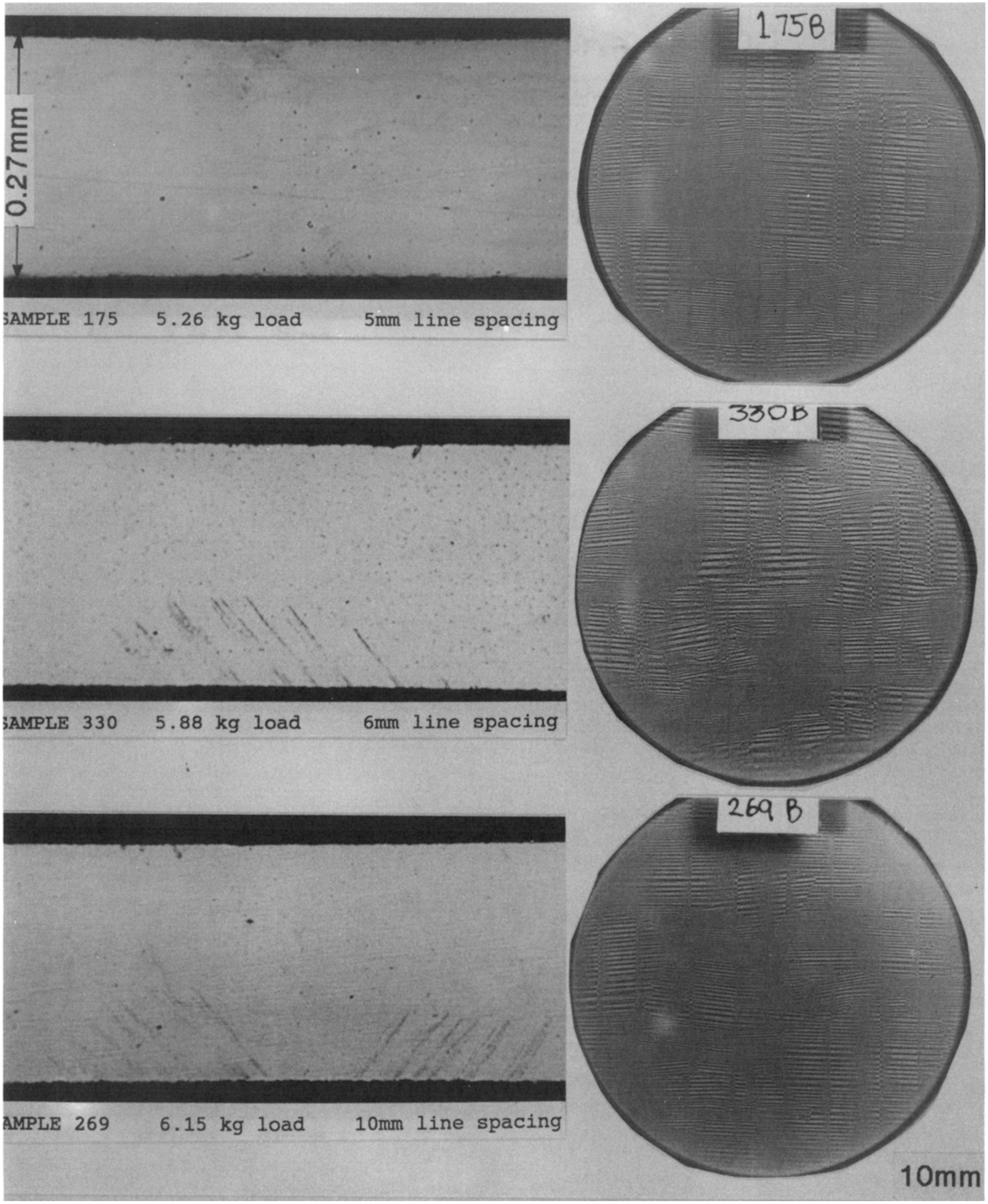

Fig. 4 Photographs of etch pits and domain structures in three samples

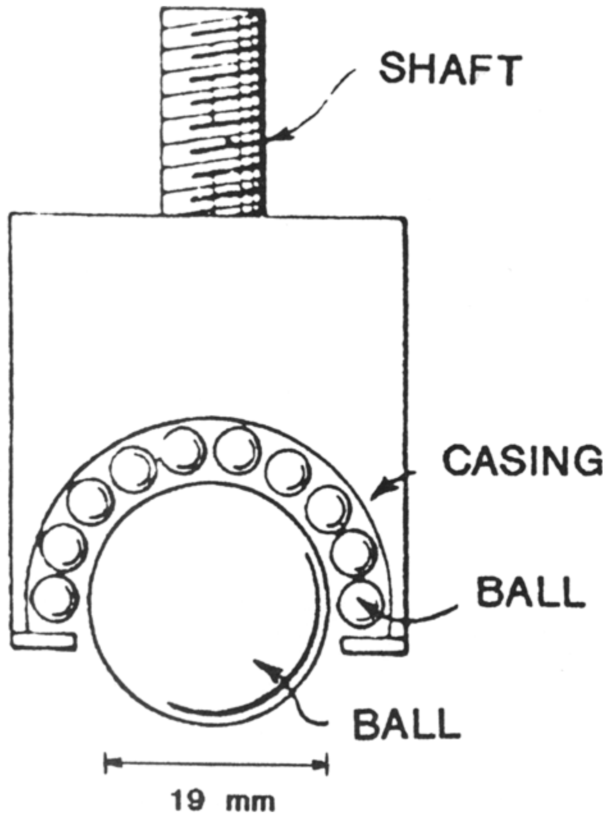

Fig. 5 Typical ball unit assembly

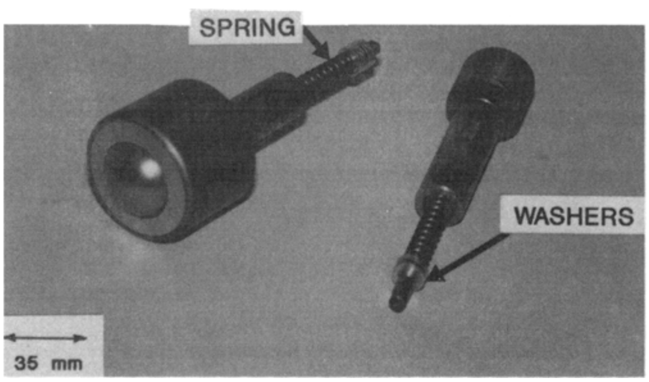

Fig. 6 Spring and washer arrangement

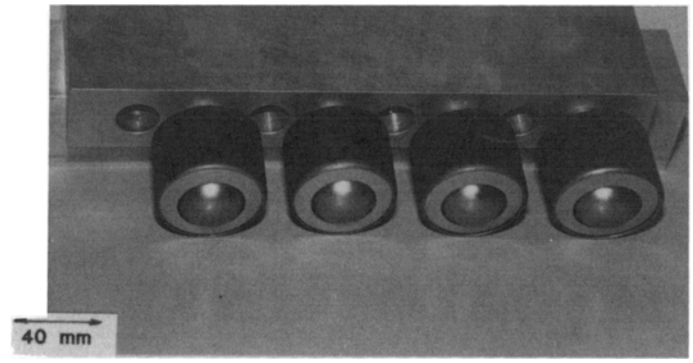

Fig. 7 Layout of ball units in support plate

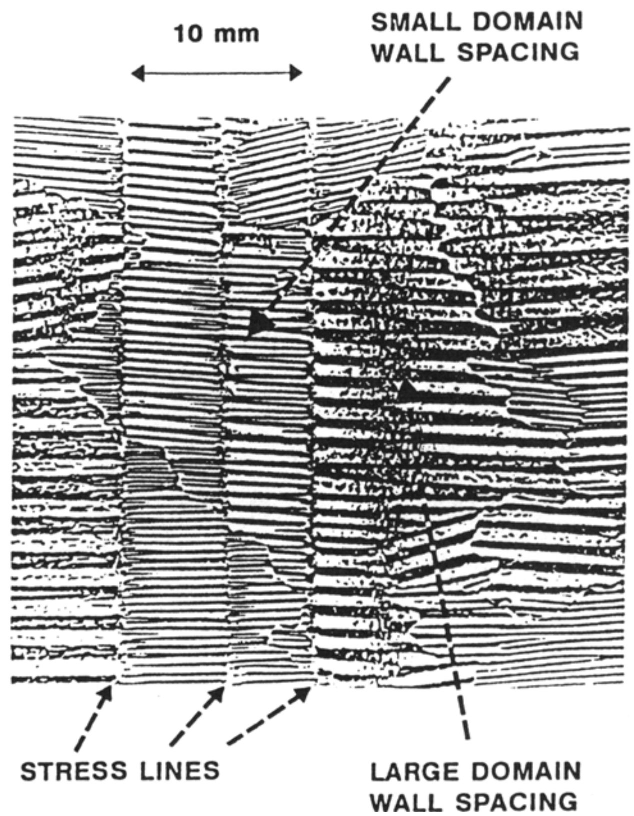

Fig. 8 Domain refinement achieved on a sample that has been partly treated (left)

into a conventional thermal flattening and coating line for grain-oriented steel.

2.2 *Method*

Small-diameter balls (0.7 mm) have been used to "scratch" the surface of steel to create domain refinement. However, this disrupts the insulative coating, necessitating an expensive recoating treatment (Ref 5).

If a steel ball of comparatively large diameter (e.g., 20 to 40 mm) is rolled over steel under controlled load (Fig. 2), it theoretically experiences point contact with the steel surface. However, both the ball and the steel have finite Young's moduli, so as the ball rolls the region of contact is a stripe. The hardness of the ball can be some five to eight times greater than that of the steel sheet, and thus the ball will be of much higher modulus. Grain-oriented electrical steel is strongly anisotropic in terms of modulus and tensile strength, so the stress and strain tensors beneath a loaded ball are very complex.

A simple representation of the process is shown in Fig. 3. A plot of stress versus distance across the impressed-contact stripe rises to a level beyond the steel strip elastic limit at the center of the stripe. In this region, slip occurs and permanent

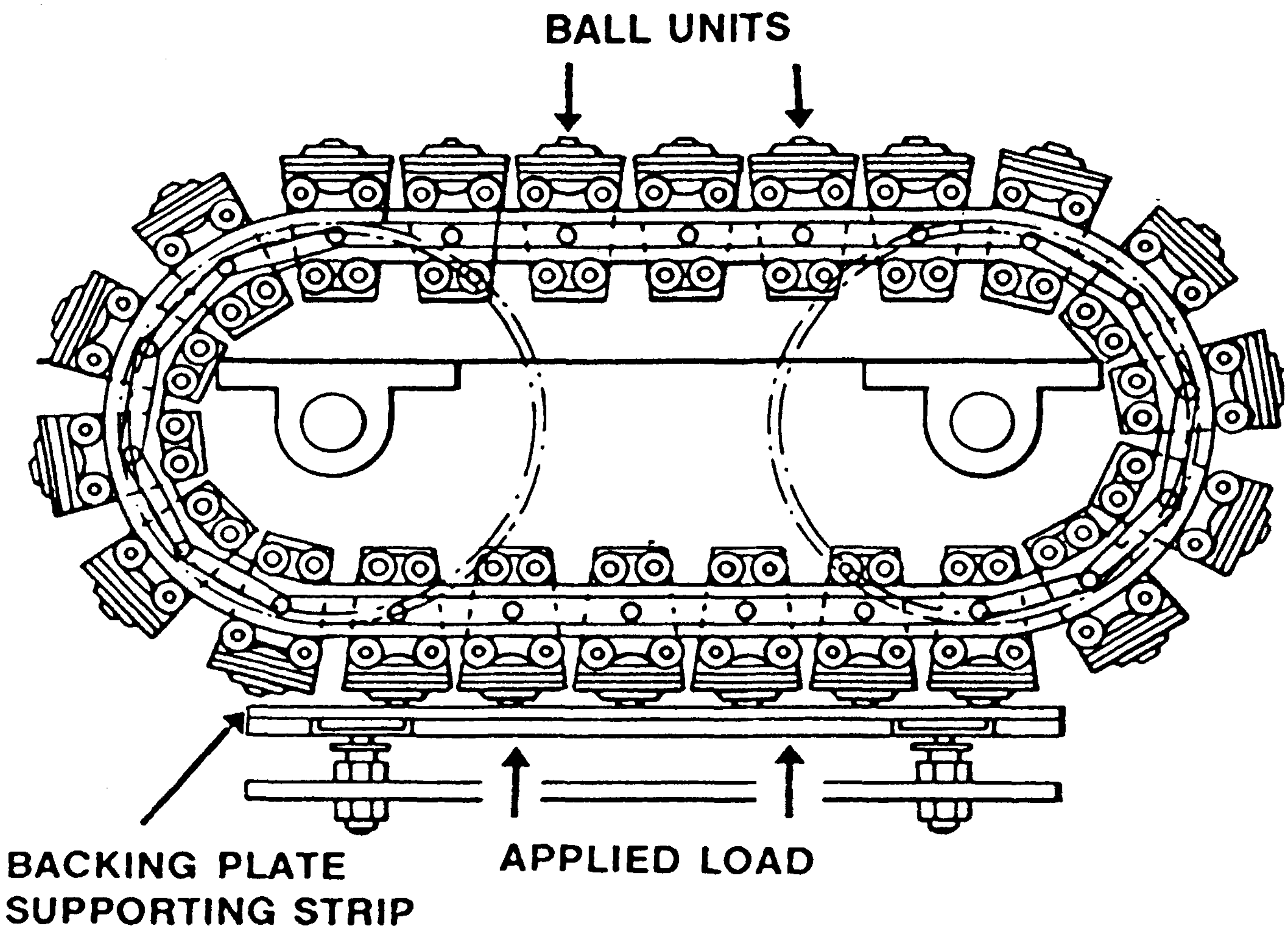

Fig. 9 Arrangement for commercial application

Table 1 Loss reduction data for 0.27 mm electrical steel sheet

Ball diameter, mm	Line spacing, mm	Applied load, kg	Power loss, W/kg (B = 1.7 T, 50 Hz) Before	After	Reduction, % Loss	$\hat{B}$1kA/m
12.7	10	4.56	1.069	0.988	7.58	0
	10	4.56	1.108	1.007	9.11	0.15
19.1	10	5.21	0.994	0.927	6.74	0
	10	5.21	1.057	0.955	9.65	0.20
	10	5.82	0.988	0.920	6.88	0.10
	10	4.68	0.975	0.916	6.02	0
	5	4.68	0.975	0.912	6.50	0
25.4	7.5	5.86	0.993	0.937	5.64	0.15
31.8	10	5.55	1.095	1.001	8.58	0.10
	10	5.55	1.034	0.969	6.29	0.10
	7.5	6.14	0.986	0.925	6.20	0.16
39.7	10	6.48	0.984	0.934	5.15	0.10

stress remains to act as a domain wall pinning line, which simulates the presence of a grain boundary.

Figure 4 illustrates the production of slip lines in a ball-treated strip. A chromic-acetic acid etch was applied after electropolishing and the sectional micrographs were taken at 45° to the strip rolling direction to facilitate visibility of the slip lines.

Figures 5 to 7 illustrate the type of ball mount used. A long spring is used to apply the loading force to the ball, thus reducing the sensitivity of loading force to steel sheet thickness and similar vertical movement to insignificant levels. The coating is not damaged during ball stripe production, and adherence and insulative properties are unimpaired.

3. Performance

Figure 8 shows the domain refinement produced on a sample that has been partly treated. An Orb powder suspension domain viewer was used to show this refinement (Ref 6, 7).

Table 1 shows typical magnetic improvements produced by ball treatment. Power loss of 0.27 mm material is reduced by some 5 to 9% without significant damage to $\hat{B}$1kA/m values.

The thinner the grain-oriented sheet, the more responsive it is to domain refinement. The ball unit method will be particularly effective for steel with a thickness of 0.23 mm or less.

4. Mechanical Realization

A pilot line is being established for application of ball unit treatment on a large scale, employing an overhead "racetrack" technique (Fig. 9). The process is the subject of various patent applications (Ref 8, 9).

5. Conclusions

Ball treatment offers a rapid, inexpensive method for domain control of high-permeability grain-oriented electrical steel. It can be applied on standard steel finishing lines without damaging insulative coatings.

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