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APPLICATIONS AND TRENDS OF ELECTROSLAG TECHNOLOGY IN JAPAN

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INTRODUCTION

Electroslag welding and casting processes have been used in Japan for approximately two decades, with generally good success. This report describes the amount of electroslag welding performed in Japan in 1981 along with typical product applications. It also describes briefly an electroslag casting and an electroslag overlay process, as well as recent trends in the usage of electroslag technology. A brief discussion of the reasons for the trends is also included.

ELECTROSLAG WELDING

Professor Isao Masumoto of Nagoya University reviewed the application of electroslag welding in Japan in 1981 [Masumoto *et al.* (1981)]. His survey, which does not claim to be comprehensive, but appears to include most of the larger users of electroslag welding, indicates that more than 250 tons of electroslag weld metal was deposited in 1981. This was estimated to be 0.064% of the total volume of weld metal used in Japan; hence, in Japan, electroslag is a specialized process which is used for a limited number of applications. Nonetheless, Japanese industry has a wide range of experience with the process. Welds of 0.3 m to 9 m length have been made in section thicknesses ranging from 16 mm to 2.1 m. Welding currents range from 280 A to 8000 A with joint gaps from 18 mm to 50 mm. Materials welded include mild steel, high strength steel, stainless steel, and Cr-Mo steels. As can be seen from Figure 1, three-quarters of the weld metal is produced by the nonconsumable electrode guide process and most of this is used by the industrial machinery and pressure vessel industries. It should be noted that these overall figures are heavily biased by several 2 m x 4 m x 50 mm joints made in large castings for the industrial machinery industry. Each such weld contains over 10 tons of weld metal which is 4% of the total annual electroslag usage in Japan! Although, Professor Masumoto's report does not indicate actual figures, it is believed that the shipbuilding and building construction industries produce the largest number of ESW joints, but these are of considerably smaller average size than those of the industrial machinery and pressure vessel industries.

Typical applications for electroslag welding in Japan include the following:

- longitudinal stiffners of the upper deck of ships (see Figure 2a),
- joining of large castings (see Figure 2b, 2c, and 2d),
- longitudinal welds in cylindrical pressure vessels,
- shells for blast furnaces and basic oxygen furnaces, and
- corner joints and tee joints in building box columns.

It can be appreciated that most of these applications involve low strength steels. When higher strength steels are used or greater toughnesses are required, complete normalization is necessary (e.g., the water turbine in Figure 2d and the pressure vessel). Indeed, the greatest limitation of electroslag welding in Japan is the poor fracture toughness of the weld heat affected zone. As a result, ESW is used only where toughness is not a concern, or where renormalization is not a prohibitive expense.

In the past few years, there has been much greater use of high strength steels in

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Japan (greater than 60 ksi yield strength) The high heat input of ESW is generally not acceptable for these steels and narrow gap and electrogas processes are being used. In a January 1985 summary of welding processes for 22 major industrial products, Mitsubishi Heavy Industries listed electroslag as a current process for only three products with a projection for the future that ESW will be used in only one application, *viz.* steel rolling mill stands. Narrow gap welding will replace ESW in both of the other current applications because it is becoming faster, cheaper, more amenable to repair, and produces better weldment properties than ESW.

Japanese welding experts are unanimous in their belief that the low fracture toughness of the weld zone is the greatest barrier to increased utilization of ESW in Japan. The second most difficult problem is repair of weld restarts, although this is a minor problem compared to the question of toughness. A former problem was hydrogen cracking; but, as in the United States, this has been solved by better process control.

Japanese investigators have tried a number of methods of reducing the toughness limitation. Process variations to reduce heat input, e.g., metal powder additions, reduced joint gap, multiple electrodes and the like have been made, but are not deemed to be of sufficient magnitude or practicality to solve this problem. For some steels, the twofold reduction in heat input permitted with electrogas welding is sufficient to improve toughness to acceptable limits, but for most steels, narrow gap is the best welding process which provides good toughness. In a few applications, electron beam welding is preferred but this process, like ESW, is very specialized.

In summary, Japan has a great deal of experience with electroslag welding of steels. The process works well, but the degradation of mechanical properties due to the high process heat input, limits ESW to a few specialized applications. Current trends indicate less use of ESW in favor of narrow gap, electrogas, or electron beam processes. This trend is accelerated somewhat by the increased use of higher strength steels which have more restrictive heat input limitations.

ELECTROSLAG CASTING

Although there appears to be considerably less experience in Japan with electroslag casting as compared with electroslag welding, Mitsubishi Heavy Industries has considerable commercial experience with a process called "yozo" which can be translated as "melt forming." Both large diameter pressure vessel cylinders or small diameter tubes can be produced by variations of this process as shown in Figure 3a and 3b. A number of interesting production materials and shapes have been made using this technology in Japan. These include oval tubes of HK40 alloy, heavy section "H" beams of 25Cr-35Ni-2Mo heat resistant steel, bent steam reformer tubes of varying wall thickness and large diameter stainless steel elbows. The product quality is excellent. The only difficulty is that the electroslag casting process is relatively slow compared with alternative casting processes. With the advent of AOD and VOD refining techniques to steel casting technology in recent years, it appears that the use of yozo electroslag forming is rapidly declining for economic rather than for technical reasons.

As with electroslag welding, electroslag casting in Japan is declining; however, it is a technically sound process which may have a number of advantages in specialized applications.

ELECTROSLAG SURFACING

One of the areas of electroslag technology where applications are increasing is surfacing. This process, called MAGLAY, was developed by Kawasaki Steel in the late 1970s and is now used extensively in Japan and has been licensed to several European manufacturers. As far as the Japanese know, there has been relatively little interest in this development from the United States.

The MAGLAY process is a strip cladding process in which high electrical conductivity flux (containing greater than 50% fluorides) is used to promote electroslag rather than submerged arc performance. This process was studied extensively in Europe in the early- to mid-1970s, but the major problem was undercutting at the overlap regions between weld deposits. Kawasaki Steel recognized that this undercutting was due to an unfavorable convection pattern in the liquid metal and slag. By introduction of external magnetic coils, they were able to alter the normal convection pattern and eliminate the undercutting (see Figure 4). The result is a very uniform weld overlay bead with exceptional smoothness. In addition, the low heat intensity of the electroslag process, as compared with the submerged arc process, greatly reduces dilution which is an advantage in cladding operations. The usual strip cladding width with MAGLAY is 150 mm, but 300 mm wide coils have been used successfully. Since its introduction, some four or five years ago, MAGLAY has overtaken virtually all cladding operations in Japan. Submerged arc cladding is only used in some specialized operations where higher dilution is desired or on complex curvatures, such as conical heads. In these later cases, narrower beads must be used and the higher heat intensity of the submerged arc process permits more rapid travel speed. In most cases, where bead width is not restricted by vessel geometry, the MAGLAY process is preferred. The travel speed of MAGLAY is slower than submerged arc but the practical bead widths are greater.

SUMMARY

Japanese industry has considerable experience with electroslag technology in a wide range of materials and product sizes. The process is generally considered to operate well, but its uses are declining in most cases. In the case of electroslag welding, the major disadvantage is the low fracture toughness in carbon and low alloy steels due to the high process heat input. Narrow gap, electrogas, and in some cases electron beam welding processes are increasingly preferred due to lower heat inputs, similar costs, and more versatile positional capability.

Electroslag casting in Japan has never been a major technology, but in recent years it has been nearly totally replaced by other processes which can refine the metal much more rapidly and economically. One exception is the MAGLAY electroslag surfacing process which has gained rapid acceptance in the pressure vessel industry.

There has been relatively little research on the electroslag process in Japan for nearly a decade. One expection is that descibed by Nakano *et al.* (1978), which was apparently done in conjunction with development of the MAGLAY process. Indeed, some Japanese researchers question why the United States is still interested in ESW. As far as they are concerned it is a well understood but limited process of declining interest. At a welding society meeting held in November 1984, attended by representatives of some 40 Japanese companies, only two companies noted current use of electroslag welding, and these two applications both involved joining of castings.

There is some interest, but no research experience, on electroslag technology for titanium in Japan. Kawasaki Heavy Industries and Mitsubishi Heavy Industries are competing for a contract to build a 2-m-diameter, 60-mm-thick spherical titanium submersible. The tenative welding process is electron beam, but the researchers were interested to learn that ESW may be a good process for titanium. In the area of electroslag casting, several Japanese steel companies would like to make large, rectangular titanium castings for production of rolled heavy section titanium plates. At present, such work is only in the planning and basic research stage. It is not known whether electroslag casting of titanium would be considered for production of such shapes.

In conclusion, Japanese experience with electroslag technology is broad, but its use is declining in favor of other processes. There is no evidence that this trend will reverse in the future.

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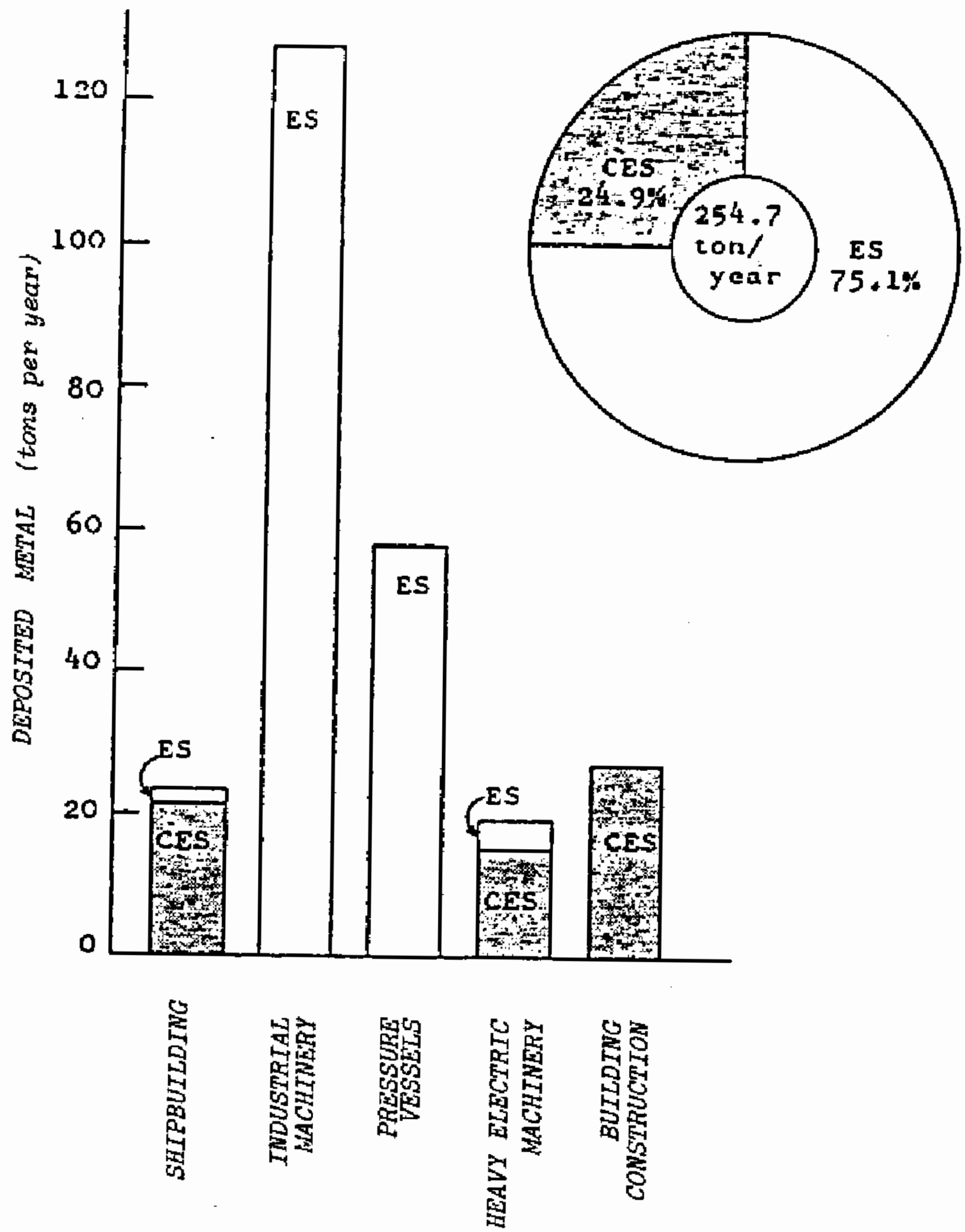


Figure 1. Weight of electroslag weld metal deposited in Japan in 1981. [Masumoto *et al.* (1981).]

CES - Consumable guide process
ES - Copper electrode guide process

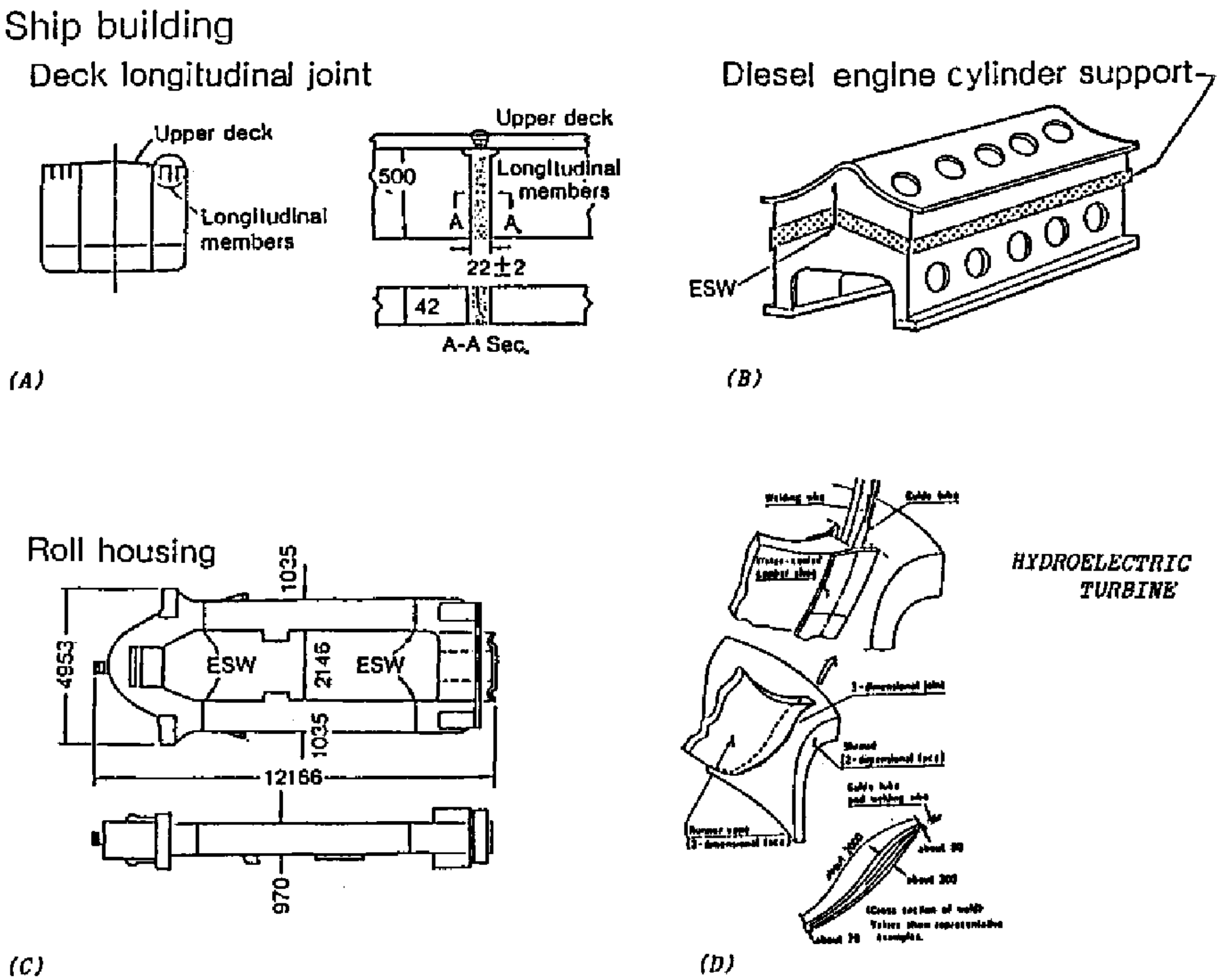


Figure 2. Examples of product applications using electroslag welding in Japan. Note all dimensions are in millimeters. [Masumoto *et al.* (1981), Sato *et al.* (1983).]

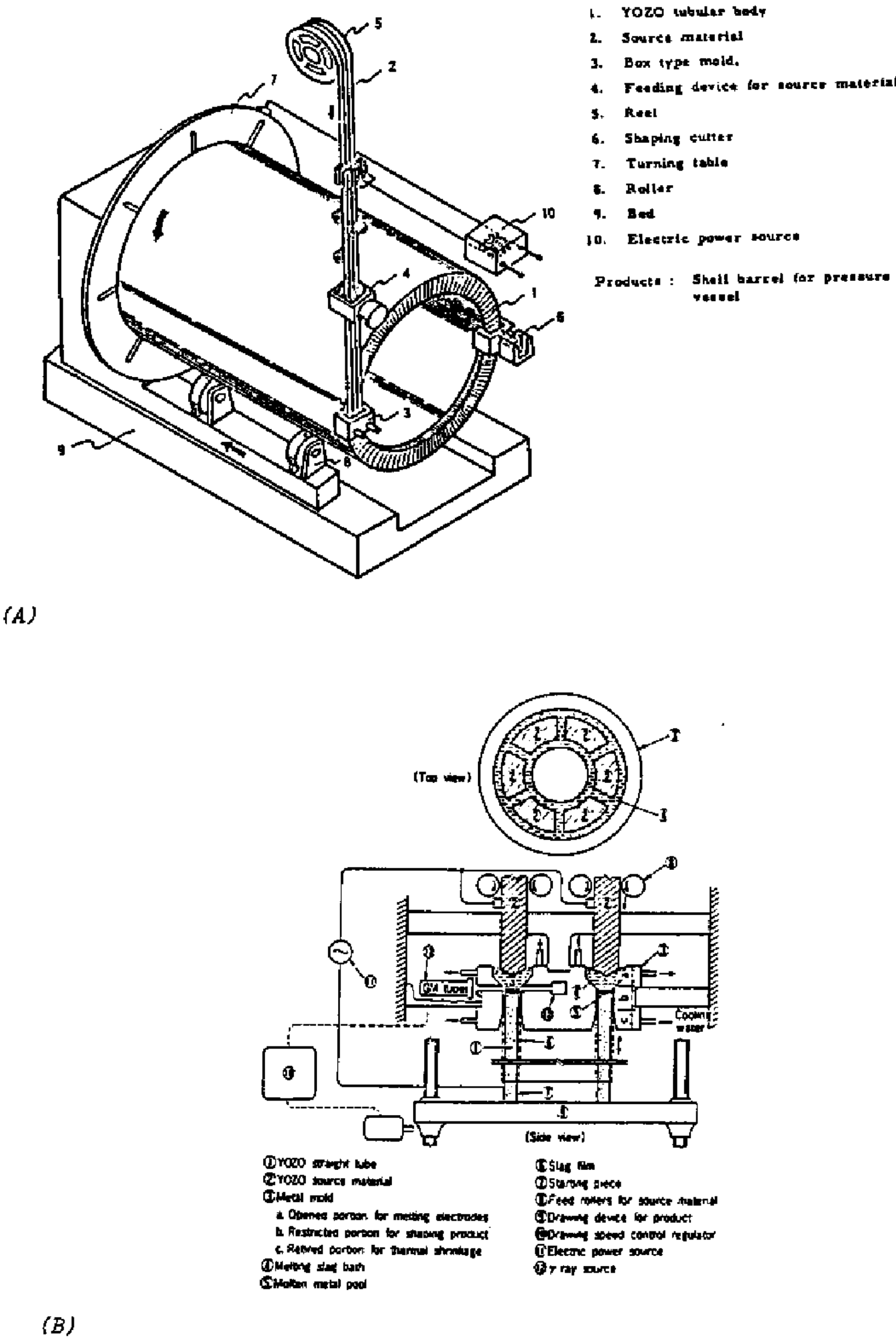
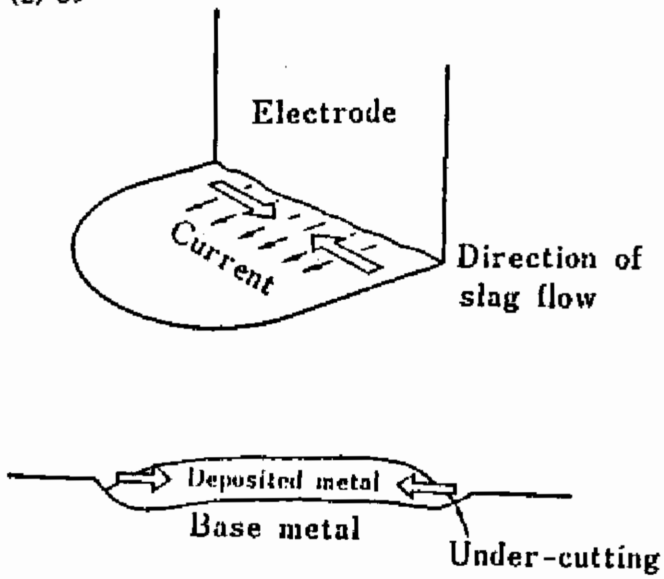
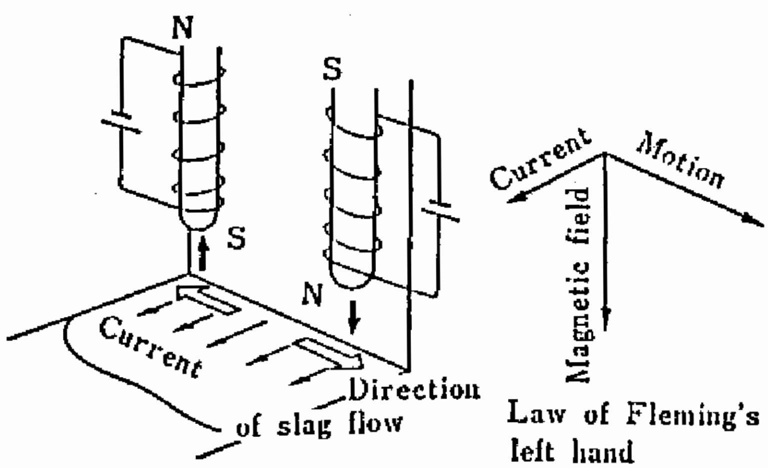


Figure 3. Examples of electroslag casting of tubular shapes by the yozo melt forming process. (Ujiie *et al.* (1968), Sato *et al.* (1983).]



(A) Schematic mechanism of under-cutting caused by parallel welding current



(B) Control of slag flow with outer magnetic field

Figure 4. Principle of operation of MAGLAY electroslag surfacing process. Addition of electromagnetic coils alter the convection pattern and eliminate undercut. [Nakano *et al.* (1978).]