Electroslag Welding of 75 to 100 Ton Ingots

by

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The principle of electroslag welding is not new. For many years the techniques of heat generation by passing an electric current through a molten slag has been known. The general scheme includes some method of containing the molten slag pool between the components to be joined with the electrode tip immersed in the liquid slag. The current passing between the electrode and the base metal heats the melt to a very high temperature and increases the electrical conductivity of the slag. The slag pool temperature exceeds the melting point of the base and filler metal. The molten base metal and filler metal then collect below the slag pool and together make up the weld pool. As this metal solidifies it joins the previously mentioned components and is what we refer to as the weld area.

Much work has been done in ESW throughout the world during the past twenty years especially in the USSR. With the continuing advances in the state of the art in ESW has brought about a new remelting technique called Electroslag Remelting.

Work in the USA was carried on by Hopkins at Furth Sterling using a DC process. Work was also being carried out on a large scale a Paton Institute at Kiev under Drs. B. Paton and B. I. Medivar using both DC and AC. The material obtained by the ESR process showed improvement in elongation, reduction in area, impact strength and fatigue strength over conventionally melted material (open hearth and Electric Furnace). During the 1960's and the early 1970 people throughout the world were continually working on increasing the size of ESR ingots. By late 1971 ingots of 40 to 80 tons had been produced.

The question continuously arises, how big can you produce ESR ingots? At present two furnaces are nearly operational for large ingots. One is to produce 100 ton ingots and the second 150 ton ingots. When one considers large turbogenerators these values are small. To day companies are pouring 375 ton static cast ingots for turbogenerators. There are real problems associated with large ingots like these such as shrinkage and liquation which results in severe defects in ingots. These large ingots after processing produce finished shafts with a weight in the neighborhood of 175 to 200 tons or about 55 to 65% of ingot weight. It has been proved to date on ESR ingots of lesser weight that finished shafts can be obtained weighing 80% of ingot weight. Considering the microstructure and macrostructure control that can be obtained using the process ingots of larger weight should follow the same pattern.

Recent work at Paton Institute has shown it is possible to join large crossection components by ESW and obtain equal or better properties to the ingot itself in the following manner. Previously large sections were joined by welding using a number of wire electrodes in a consumable nozzle. It is very often possible to get improper feeding of these separate wires into the slag pool and leads to defects in the weld zone. Secondly, the wires are not of the same composition as the ingots and so the weld zone will differ in composition from the ingots. Thirdly, when welding large sections of air hardening, steels heating the components to 375 to $425^{\circ}C$ are required. Using the above method it is very difficult if not impossible to weld without heating.

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To over come this a new method has been developed which utilizes four electrodes as shown in the same figure 1. To start, the electrodes are made of the same chemical composition as the ingots. All electrodes are consumable. The outer two electrodes are rectangular where as the inner two are of square cross-section. The current supply from the transformer to the electrodes is in a bifilar manner or to 3+5 and 4+6 as shown in figure 2.

The bifilar arrangement allows for a higher power factor and reduces inductive losses. Using this method a very large amount of energy imput (0.15 kwt/cm^2) to the consumable nozzle is obtained. This very high amount of energy imput provides the necessary heating of the ingots being welded and avoids the requirements of preheating the large ingots. The arrangement is shown in figure 3 for welding a 60 inch diameter ingot. The next figure shows two 60 inch diameter, 40 ton ingots welded together.

This process has a number of advantages over any previous method including, better and more homogeneous mechanical properties, better chemical composition and structure uniformity, no reason for prior or simultaneous heating of ingots during welding. Simpler equipment and much better realiability of welding and reduction of flaws in welded joints and finally cost is lowered.

Using this process it is now possible to produce medium size ingots (100 tons) and join as many as are required (3-6) to produce 500 or 600 ton ingots which could never be produced by static casting. Also it gives very good possibilities in producing large complicated shapes by joining in this manner.

Now let us look at some of the properties obtained.

Table I gives the elemental analysis and gas content in the electrodes, ingot and weld metal utilized in the investigation. The analysis shows a very consistent composition except for a large reduction in sulphur, hydrogen, oxygen and nitrogen. This reduction is very desirable and will aid in improving the mechanical properties and fracture toughness of the material. The ratio of deformation of a large ESR ingot after heat treatment which included quenching in oil at 840-860°C and tempering at 670-680°C is given in table 2. The mechanical properties at the various deformation ratio are given in figure 5. After a deformation of 1.5 (diameter reduced 44" to 35") all mechanical properties have improved. Only impact strength continues to improve on further forging although it is more than sufficient at 1.5.

Two rotor steel ingots (Cr-Ni-Mo-V, like HY 150) were welded together using this technique. Specimens were taken along the longitudinal axis of the ingot in the ingot and in the weld zone. Specimens were also cut perpendicular to this axis in the heat effected zone. Two sets of specimens were obtained one at the periphery and the second at the center.

Table 3 gives the following properties, yield and tensile strength, elongation, reduction in area and impact strength, after an oil quench and 620°C temper.

After a 1.5 forging reduction the properties are greatly improved and the material would be very useful for rotor application with rotation speeds to 3000 rpm. This new technique will allow fabrication of very large rotors of extremely high quality and at a much lower cost.

CONCLUSIONS

The following conclusion were drawn from material presented in this paper:

1. The new process to weld large ingots is more reliable and reduces possible welding defects.
2. The large heat imput during welding alleviates preheating.
3. Chemical homogeneity of weld joints is improved.
4. Micro- and macrostructure of weld zone is similar to that of the ingot.
5. Mechanical properties of the weld metal are equal to those of the ingot.

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The author would like to thank Dr. B. E. Paton and Dr. B. I. Medovar of Paton Institute, Kiev, USSR for the information and data presented in this paper.

TABLE 1.

ELEMENTAL ANALYSIS AND GAS CONTENT IN WELD METAL

Position of sample selection	Composition, %										
	C	Si	Mn	S	P	Cr	Ni	Mo	V	Al	Cu
Open Hearth electrodes for ESW and ESR	0,25	0,28	0,44	0,017	0,015	1,57	3,2	0,41	0,16	-	0,11
Metal of ESR ingots	0,23	0,25	0,50	0,007	0,012	1,60	3,5	0,50	0,160	020	0,10
ESW Weld Metal	0,24	0,22	0,50	0,009	0,012	1,60	3,2	0,49	0,160	016	0,09

Position of sample selection	Gas Content		
	(H)	(O)	(N)
Open Hearth electrodes for ESW and ESR	0,00027	0,0041	0,0039
Metal of ESR ingots	0,0001	0,0028	0,0025
ESW Weld Metal	0,0001	0,0015	0,0020

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TABLE 2.

RATIO OF DEFORMATION

	Diameter (in.)	Forging Ratio
As Cast	44	1
Forged	35	1.5
Forged	30	2.0
Forged	26.8	2.5
Forged	25	3.0
Forged	19	5.0

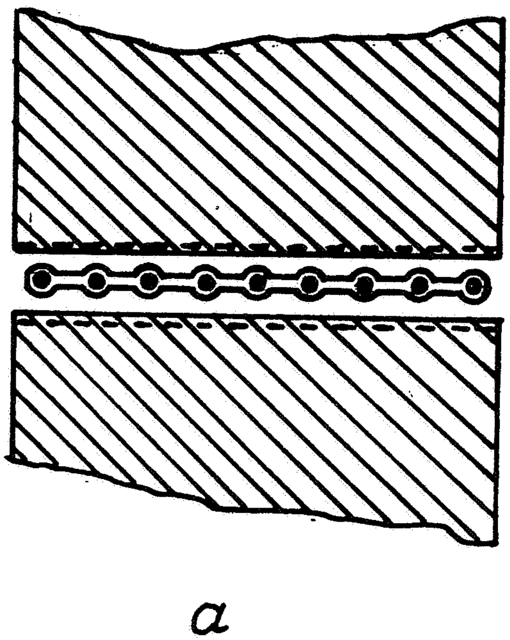
Length of Shaft 125" (10 feet)
Steps at least 18" each

TABLE 3.

Mechanical properties of welded joint of a ESR rotor steel

Specimen taken from	Deformation ratio	KSI	KSI	Mechanical properties Elongation %	Mechanical properties Reduction %	Input ft.lb/in^2
	no	125	141	16,1	45,8	499
Weld metal (weld axis)	1.5	135	148	18,1	61,7	578
	2	138	152	18,4	62,8	569
Heat-affected zone (fusion line of weld with ingot metal)	no	128	144	15,8	65,4	606
	1.5	138	151	16,9	62,5	676
	2	137	149	16,2	65,4	755
Parent metal	no	121	137	16,7	50,0	503
	1.5	135	146	19,2	66,0	746
	2	137	149	19,0	65,5	746

NOTE: Notch in impact specimens, in regions of coarse grain 1.5+2.5 mm from fusion line into direction of ingot.



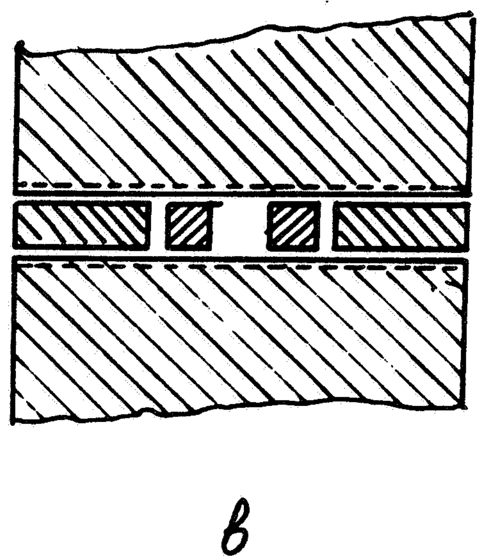
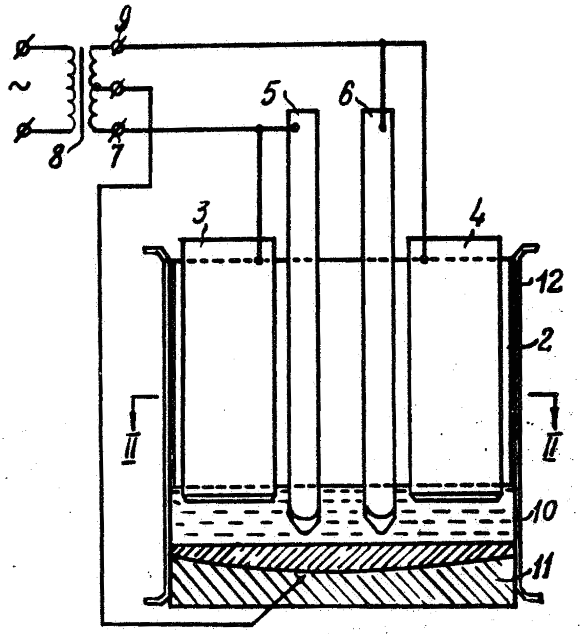


Fig.1. Diagram of electrodes location in the gap
a) - in the old ESW method;
b) - in the new ESW method.



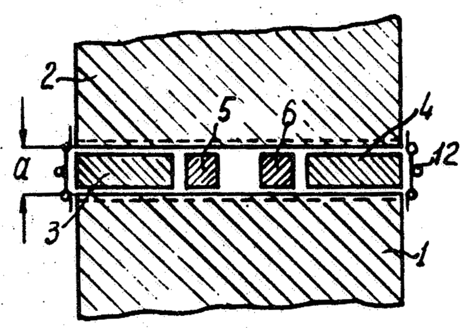


Fig. 2. Diagram of electroslag welding process of heavy sections according to the new method.

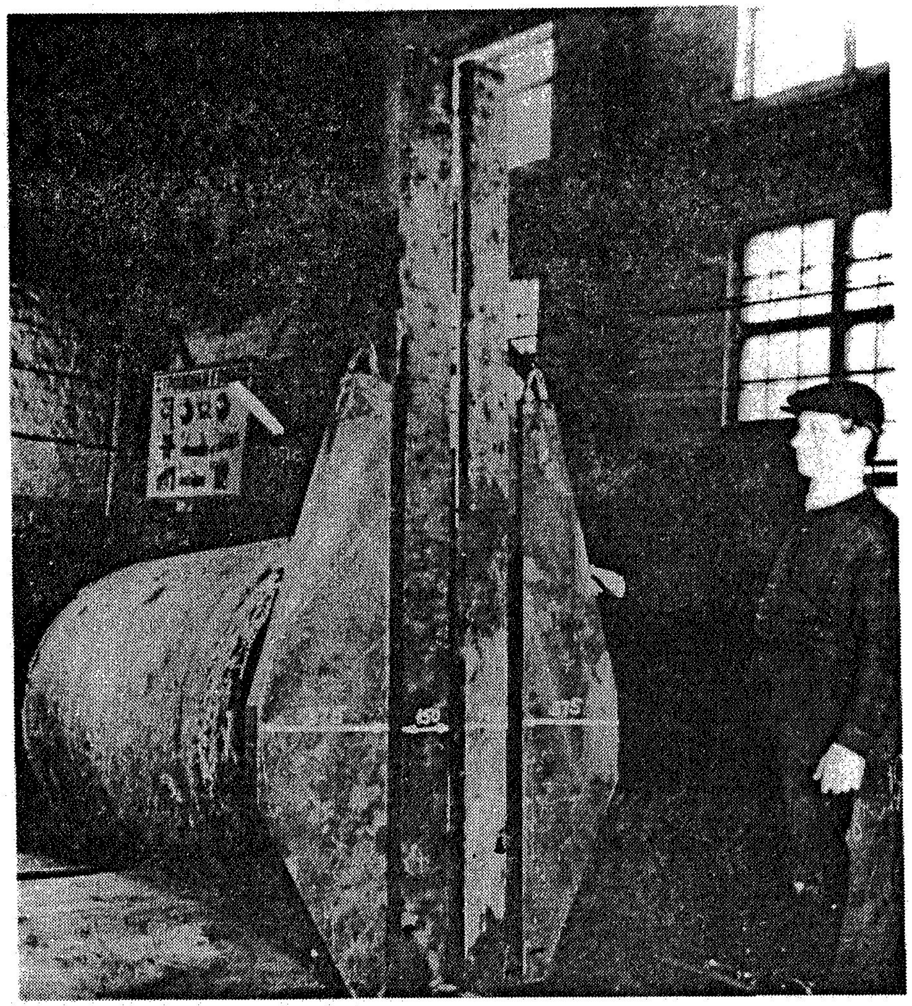


Fig. 3. Arrangement of fixed and movable electrodes in a welding gap during welding according to the new method.

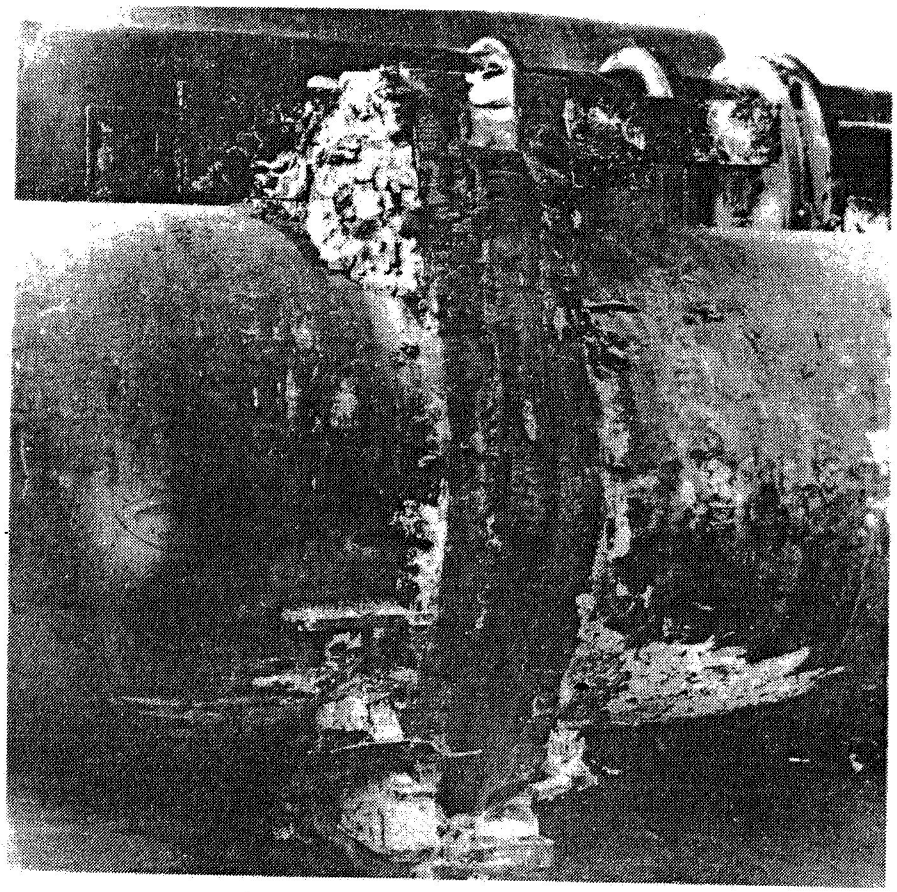


Fig. 4. Appearance of a welded joint formed by welding 40 ton Cr - Ni ESR steel ingots of 1500 mm (60 in.) dia. according to the new technology.

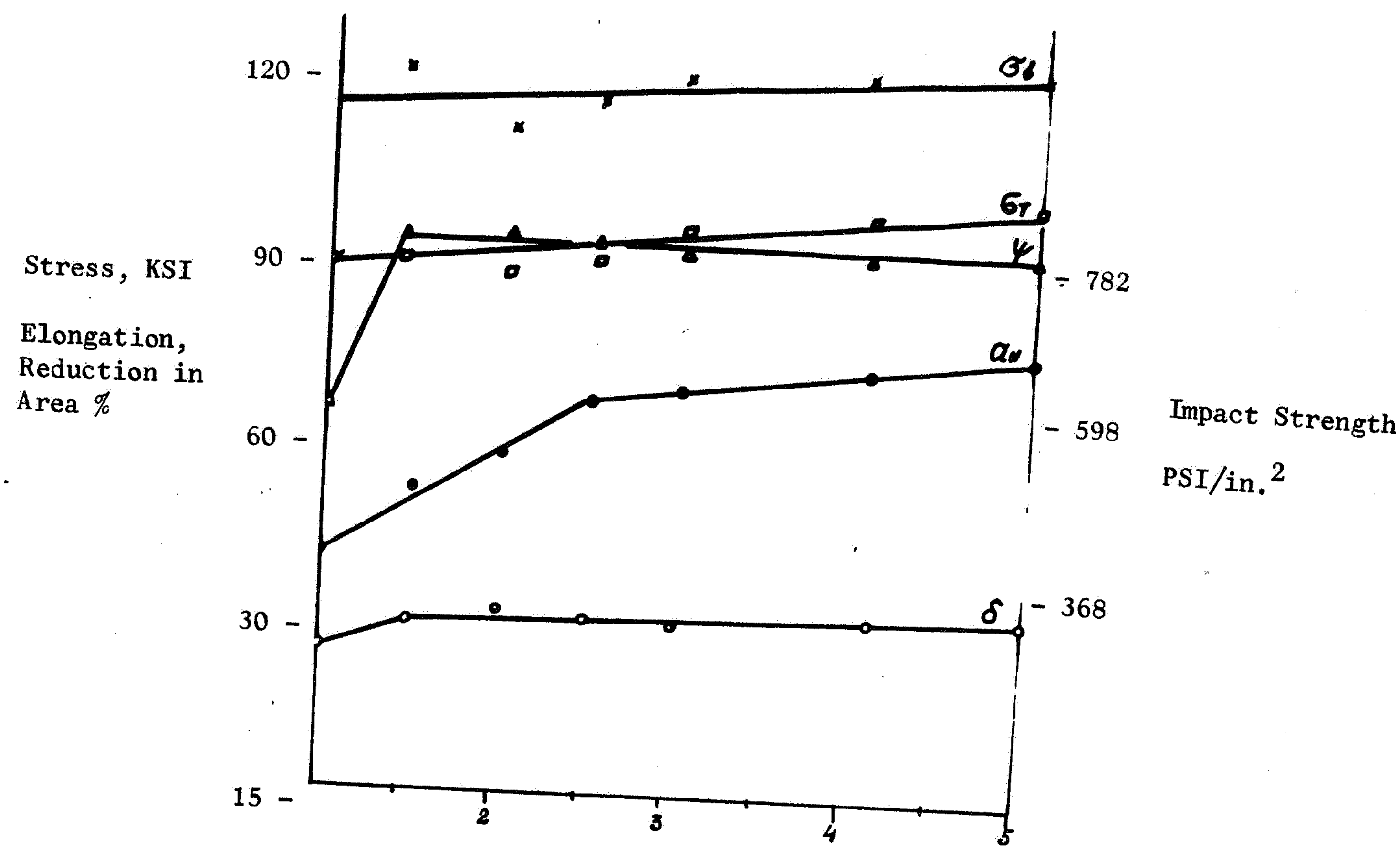


Fig. 5 . Effect of ratio of deformation on the mechanical properties of the heavy ESR ingots.