Project Report

ELECTROMAGNETIC CASTING

submitted towards the partial fulfilment of the requirement
for the award of the degree of

BACHELOR OF TECHNOLOGY
MATHEMATICS AND COMPUTING

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DECLARATION:

We hereby certify that the work, which is presented in the Project entitled **Electromagnetic Casting** in fulfilment of the requirement for the award of the Degree of Bachelor of Technology in Mathematics and Computing and submitted to the Department of Basic Mechanical Engineering, Delhi Technological University. It is carried out under the supervision of Dr. Akhilesh Arora and Dr. N K Yuvraj. The work presented in this report has not been submitted and not under consideration for the award for any other course/degree of this or any other Institute/University.

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SUPERVISOR CERTIFICATE:

To the best of my knowledge, the report comprises original work and has not been submitted in part or full for any Course/Degree to this university or elsewhere as per the candidate's declaration.

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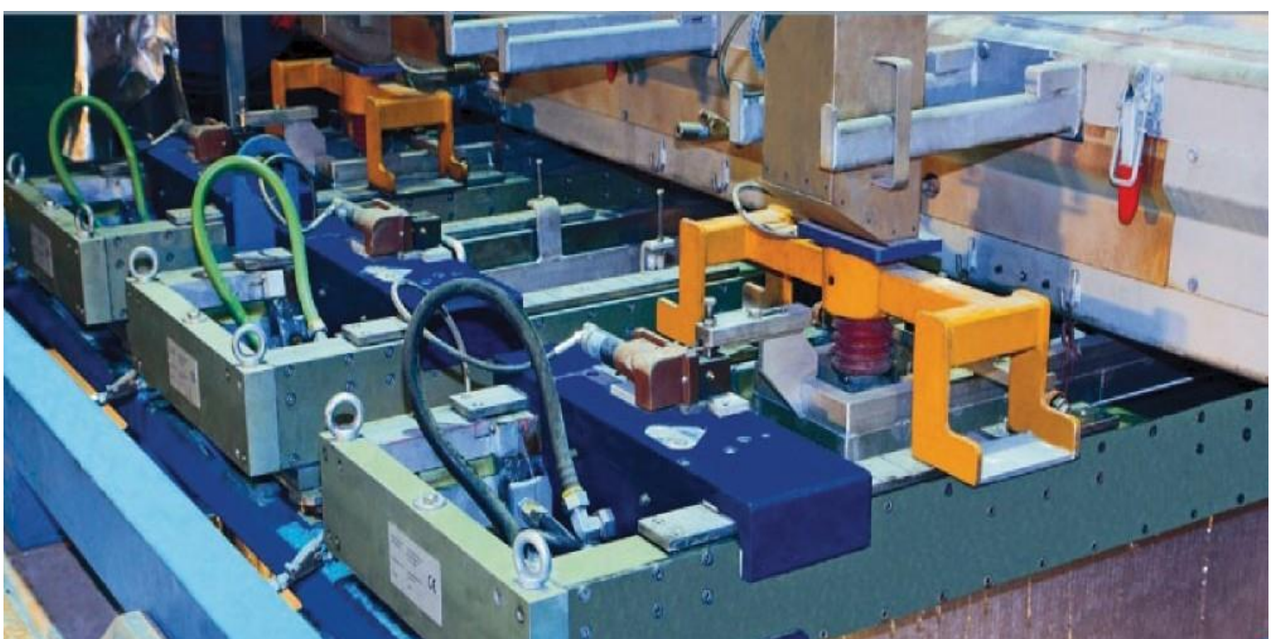
Abstract:

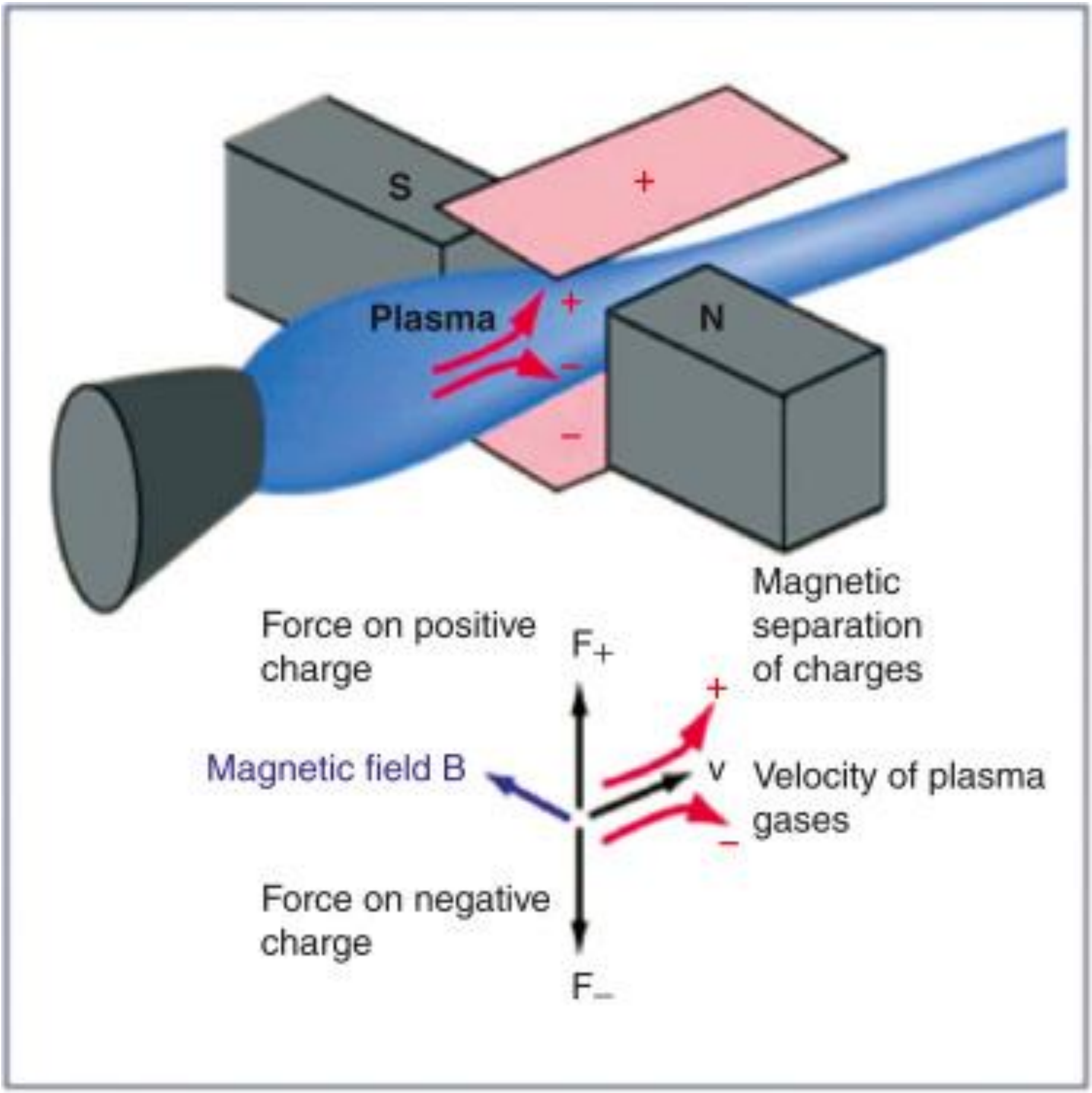
Electromagnetic casting (EMC) technology depends on the Electromagnetic force to prevent the metal from touching the mould, leaving the ingot surface very smooth. As a result, the surface imperfections, such as oscillation and subsurface segregation etc. caused by a mould of direct-chill casting (DCC), are avoided. Moreover, the electromagnetic stirring makes the structure more homogeneous over the entire cross-section. In this project, 2024 aluminium alloys made by EMC and DCC were analysed by optical microscope and scanning electron microscope, solution heat treatment and artificial ageing were given to investigate the mechanical properties such as hardness, wear-resistance and fatigue. Results showed EMC ingots had a fine and uniform grain structure, which made the EMC ingots have high hardness and good fatigue. The hardness of EMC specimens increased one time than DCC ones and the fatigue was three times as high as DCC ones in the as-cast state. The EMC specimens also expressed an excellent characterization in wear resistance the weight loss was only half of DCC specimens.



Introduction:

Electromagnetic casting (EMC) is a technology developed by combining Magneto-hydro-dynamics (MHD) and casting engineering. The casting method employs the electromagnetic forces to pinch upon the liquid metal through an alternating electromagnetic field, which is induced by an inductor. The electromagnetic forces are produced by the interaction of eddy currents induced in the metal with the produced magnetic field of the inductor. The main advantage of the EMC technology consists of the presence of stirring motion in the melt, which leads to a significant reduction of the grain size in the solidified product. Moreover, surface quality and subsurface quality are improved due to the absence of ingot mould. The surface finish of the ingots is usually smooth enough to be hot rolled without scalping operation that is required for direct-chill casting (DCC).

Aside from refining internal structures, electromagnetic stirring also has the advantages of homogenizing alloy elements, reducing porosity and segregation, and minimizing internal cracks. Because of these distinct merits of EMC technology, many scientists and engineers in different countries have engaged in the electromagnetic shaping and MHD phenomena in EMC of aluminium nevertheless, the research about the microstructure and mechanical characteristics has been comparatively few. This paper is an attempt to remedy this deficiency. The microstructure characteristics such as the grain structure are of great importance since many mechanical properties are directly related to the size, shape and distribution of the grains. As a result, the 2024 aluminium alloys were cast by DCC and EMC to investigate their microstructure and properties. Its nominal composition is Al–4.3 Cu–l.6 Mg–0.7Mn. As a kind of widely applied hardening alloys with high strength, it is often used to fabricate the plane wrappings and aero-engine vanes working under high temperature.



The diagram shows a systematic overview of Magneto-hydro-dynamics.
Using Left Hand Thumb Rule we can easily check that the magnet and current defines path of the stream by applying a force on perpendicular direction to them i.e. showing the direction of the flow of the stream.

Experimental Procedure:

Principle and apparatus of electromagnetic casting:

The experimental campaigns were carried out on a pilot-scale caster, in which trial-and-error shaping experiments were performed and the optimized technical parameters have been obtained. The basic apparatus of EMC consists of a delivery system, a casting control system, a shaping and a cooling system, a melting furnace and a power supply etc. A medium-frequency alternating current was used to generate the alternating magnetic field in the molten aluminium. This magnetic field generated a heavy eddy current on the surface of the molten aluminium in the opposite phase to the imposed current of the electromagnetic coil. This resulted in a force directing towards the centre of ingots. The electromagnetic force located within the liquid column of ingots prevented the metal from touching the mould. The technique procedures are as follows:

Melt metal adjust the position of an inductor, screen, water jacket and bottom block operate the cooling system turn on the power supply cast on at a withdrawal speed until the end of casting.

The manufacturing conditions are inductor current, 4800 A the height of the liquid column, 40 mm solidification front, 10 mm up to the bottom of the inductor pouring temperature, 710-730 °C flow rate of cooling water, casting speed. Besides the as-cast state, some 2024 specimens were solution-treated at 495 °C in a salt bath furnace for 1 h and then quenched in ice water. After this, they were immediately aged in the 190 °C silicon oil bath for various holding time to obtain the hardening effect. The metallographic specimens were prepared by cutting, grinding, polishing and etching.

The specimens from DCC and EMC ingots were examined and contrasted by optical microstructure (OM) and scanning electron microstructure (SEM).

Mechanical Properties:

Hardness test Hardness tests were performed before and after heat treatment by the load of 60 kg with the Rockwell hardness tester of F type. Take an average of seven times after omitting the highest and the lowest values.

Wear Resistance Test:

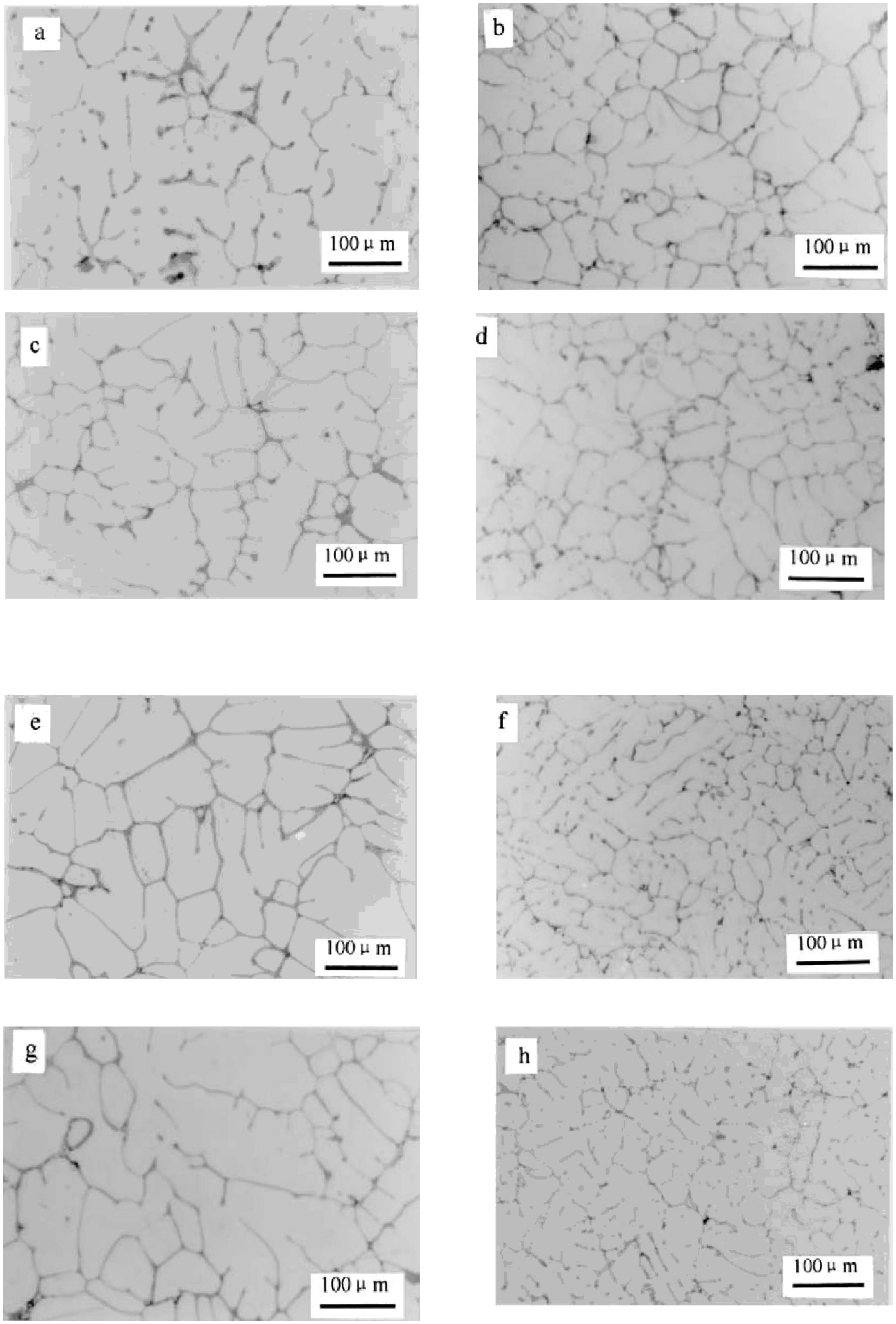
The PLINT TE88 multi-station friction and wear test machine was utilized to investigate the wear resistance of both DCC and EMC specimens. Cylindrical pin samples were machined to a length of 15 mm and a diameter of 8 mm. The disc of counterpart was made of AISI 1055 steel quenched, the load was 60 N, sliding distance 200 m, sliding speed 1 m s^—1. The weight loss of various aluminium alloys was obtained by weighing the pins before and after each run.

Fatigue test:

The castings were cut into slices for the fatigue specimens basing on the ASTM 466-96. Both as-cast and T6 specimens were tested using an Instron 8516 hydraulic fatigue test machine. All fatigue tests were performed in a laboratory environment at ambient temperature. Constant-amplitude, fully reversed loading was applied at a frequency of 20 Hz to all specimens. Tests were conducted at nominal stress of 100 MPa.

Discussions:

- The figure showed the transverse sectional grain structures of the 2024 DCC and EMC specimens in as-cast state.
- The grains of EMC were small and equi-axed at all the points no matter whether it's edge, mid thickness or centre of ingots.
- The intensifying phases S and theta are distributed along the alpha-dendrite boundary off and on.
- In DCC or direct-chill casting condition, the size of grains became coarse from the surface of ingots to the centre, with long and thick intensifying phase located among them.
- The dendrites grew and coarsened in the centre of DCC ingots due to Ostwald ripening.
- A non-uniform heat transfer generates in a conventional DCC process due to air-gap formation. Therefore, local big grains often exist on the sub-surface and segregation due to the slow loss of superheat.
- However, the grains were more homogeneous over the entire cross section in EMC or electromagnetic casting process.
- The above pattern was observed because of the strong electromagnetic stirring in the liquid pool.
- This intense forced convection promoted a fast superheat evacuation and braked the dendrite arms, which led to the grain multiplication.
- The suspended nuclei localized in the vicinity of the liquid solid interface were carried away and dispersed in a slightly super-heated melt. As a result, the crystallization took place simultaneously in most of the sump and led to the formation of a fine and uniform equi-axed structure over the entire cross-section.


a
100 μ m
b
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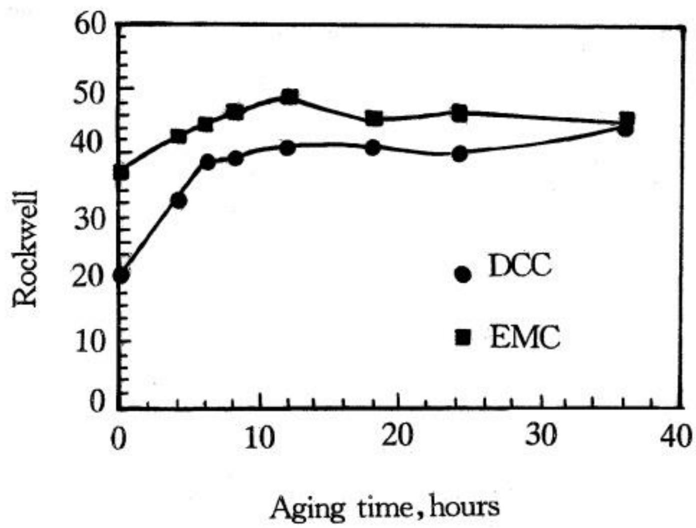
Mechanical Characterizations:

1. Hardness properties:

- The hardness of EMC specimens was two times as high as DCC ones at as-cast state.
- This huge difference in hardness led to the much finer grain structures.
- The EMC specimens reached a peak at around 12 h, while the DCC ones got the peak after 36 h.
- That clearly shows that the EMC ingots had much fast response to solution heat treatment and artificial aging as compared to the DCC ones.
- After the T6 treatment, the reinforcing phase S transformed into a transition phase S’’ and G.P. zone.
- Also the theta became a theta’’ and G.P. zone.
- At this time, a stress field caused by the strain near the transitional phase could impede the movement of the dislocation, thus could largely improve the hardness and strength of alloys.

Hardnesses of 2024 aluminum alloys

Different alloys	DCC	EMC	DCCT6	EMCT6
Hardness	16.02	31.72	20.64	37.02



Artificial aging curves of 2024 alloys: ● DCC, Rockwell; ■ EMC, Aging time (h).

Wear Resistance:

- The weight loss of DCC was higher than the EMC's in every case, no matter whether they were treated by T6 condition or not. But yeah, the heat treatment obviously increased their abrasive resistance.
- The wear debris of DCC specimen exhibited large block like particles while for the EMC ones, the wear debris existed as an aggregate of small pieces.
- No example of sheet like large particles were found in the wear debris.
- The wear resistance of EMC specimens was improved due to their fine, uniform and dense dendrite cells which could endure the friction with the wear surface.
- After the T6 treatment, the wear resistance increased in some degree. This coincides with the age hardening phenomenon.

Weight loss of 2024 aluminum alloys

Different alloys	DCC	EMC	DCCT6	EMCT6
Weight loss (mg)	3.0	1.6	2.0	1.0

Fatigue Life:

- On closer observations, it was found that the fatigue cycle number of EMC specimens was almost three times as high as that of DCC ones in as-cast state.
- It is well known, that the fracture initiates from the rough surface, sub-surface porosity, micro-pores and oxide inclusions.
- The EMC ingots have smooth surface, free of porosity and little subsurface segregation, so there is an excellent fatigue life.
- On closer observations, striated fracture of DCC specimens was observed while there was dimple rupture in case of EMC ones.
- The DCC structures indicated the cleavage-like mechanism while the EMC structures showed the ductile characteristics.

Fatigues of 2024 aluminum alloys

Different alloys	DCC	EMC	DCCT6	EMCT6
Cycle number	37484	94674	612853	735567

EMC and cost efficiency:

Advantages of the direct combination of EMC technology with the rolling process:

If we consider the economics of EMC technology purely from the perspective of the cast house, then a false picture could result. For as compared to conventional casting technology, the EMC process has a number of disadvantages:

- High investment costs.
- Complex plant automation.
- High running costs due to the electrical energy requirement.
- The need for comprehensive know-how.

However, if we extend this limited field of vision to include the further processing phases included in subsequent rolling, these problems can be clearly counterbalanced. In the final analysis, the economic advantages generated by EMC technology are as follows:

(i) The reduction or avoidance of edge cracking during hot rolling:

During hot rolling, conventionally cast, hard alloy rolling ingots are subject to highly prevalent edge cracking. This leads to an increased volume of edging scrap and a considerable reduction in the working width of the hot strip. Edge cracks derive from the presence of a distinctive casting shell on the narrow face of the rolling ingots. This reduces surface strength and thus leads to the formation of cracks caused by the forces exerted during hot rolling.

The only help in this situation is the use of an edge-milling device, but as a result of limited throughput and increased demand for material removal, this is uneconomic. By contrast, owing to their smooth cast surfaces, rolling ingots derived from EMC technology do not require any upstream edge milling.

(ii) No necessity for milling prior to rolling:

No primary cooling is used in the EMC technology. Therefor no separation of the strand shell from the surface of the mould takes place, which logically enough also means that so-called re-melting of the already solidified strand shell with the formation of a segregation zone is avoided. For these reasons, EMC rolling ingots have a smooth cast surface and a cell size that increases steadily from surface to core, which makes surface milling unnecessary. The enormous potential of EMC tech

Conclusions:

- The EMC ingots owned much fine grain size and homogeneous structure and much effective response to aging for 2024 EMC ingots compared to the DCC ones.
- The EMC ingots not only had better mechanical properties in as-cast condition but also in T6 one.
- The fatigue life of EMC ingots was about three times as high as that of DCC one in as-cast state due to the fine equi-axed grains and absence of micro-porosity of EMC ingots.
- EMC specimens expressed excellent characteristics in hardness and wear resistance.
- The weight loss was only a half of DCC ones as compared to EMC ones.
- There is reduction or avoidance of edge cracking during hot rolling in the EMC Casting Process.
- No necessity for milling prior to rolling in EMC casting process.

References:

- Cao Zhiqiang *, Jia Fei, Zhang Xingguo, Hao Hai, Jin Junze, Microstructures and mechanical characteristics of electromagnetic casting and direct-chill casting 2024 aluminum alloys, Materials Science and Engineering A327 (2002) 133–137
- EMC technology raises quality and cost efficiency, AluReport 1/2010

THANK YOU !!!!!