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Ladle Furnace Refractory Lining: A review

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Abstract: The steel-making process offers a clean, efficient, and flexible way to convert molten iron into steel. There are several types of commercially available ladle on the market according to capacity end-product, economics, reliability, and availability requirement. In many of these ladles, the service life of refractory linings has been considered as a critical barrier to ladle system. For producing higher plant capacity and superior quality a combination of refractory linings plays an important role in steel manufacturing unit. The refractory linings in these ladles are subjected to a severe operating environment and therefore need some preparation for continuous, trouble-free ladle operation. In this paper, the effect of various refractory combinations on the ladle system is reviewed.

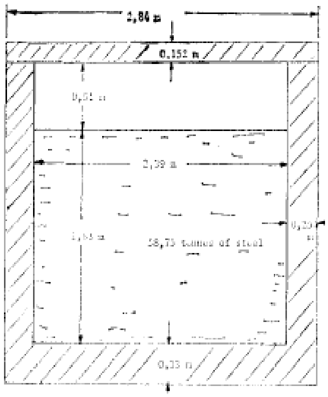
Keywords: Heat loss, Ladle Furnace, Refractory Lining, Optimization, Steel manufacturing.

1. INTRODUCTION

Steel industries are important for the development of a nation. In steel plant we use different types and capacity of ladle furnace for producing different kind of steel according to the application. In ladle furnace a large amount of heat is lost to the surrounding through conduction, convection and radiation, therefore to maintain the temperature of molten steel we use a combination of refractory material which can reduce the heat loss.

The process of casting molten steel into semi finished shapes in a continuous fashion is called continuous casting. These unfinished shapes are then ready for desired shapes and structures to be made from them. The process is called continuous casting because molten steel is cast into slabs continuously without the need for stationary moulds**[1].** More time consumed during casting means more energy required to keep the molten steel at the desired temperature and this in turn meant higher cost. Molten steel is poured continuously from a ladle into the tundish used to feed molten metal into a water cooled copper mould where the skeleton of the slab is formed. The semi cooled slab then slowly rolls out through the copper mould and in this way, a continuous steel strand is formed which is then cut into pieces once the steel slab is completely solidified.

R. C. Urquhart, R.I.L, Guthrie, A.R.S.M, D.I.C. and D. D. Howat **[2]** have investigated the case of a teeming ladle filled from a steelmaking furnace and ready for subsequent use in continuous casting or in the production of steel ingots. The purpose of this paper is to present a general formulation of the problem, the solution of which should permit the definition of the relative amounts of heat loss from the molten metal and the rate of temperature loss by the metal during teeming. The variables those have been investigated include initial steel temperature, geometry, thermal properties, and various modes of preheat. For simplicity, the ladle is regarded as cylindrical. The molten metal is added to a ladle having a preheat that is assumed to be uniform throughout the ladle refractory. The problem is to calculate the net rate of heat loss from the molten metal as a function of holding and teeming time at various ladle geometries, initial temperature distributions, and thermal properties of the system.



Initial metal temperature	1 540 °C
Ladle preheat	400 °C
Cover preheat	21 °C
Ambient temperature	20 °C
Thermal conductivity	0,002 5 cal cm^{-1}s^{-1} °C^{-1}
Heat capacity of refractory	0,156 cal g^{-1} °C^{-1}
Thermal diffusivity of refractory	0,008 05 cm^{2}s^{-1}
Heat capacity of molten steel	0,184 cal g^{-1} °C^{-1}
Molten steel emissivity	0,28
Refractory emissivity	0,75
Density of molten steel	7,20 g cm^{-3}
Density of refractory	1,99 g cm^{-3}
Casting rate	1,47 t min^{-1}
Holding time	40 min

Fig.1.1 Dimensions of the refractory ladle, and the data

G. M. Zaki and A. M. Al-Turki **[3]** stated that the use of insulation materials to decrease heat transfer to/from surfaces has been in practice for many years. Recent concerns of energy conservation and awareness of the limited energy resources encourage revisiting the problem of thermal insulation. The thermal insulation design economics has been reviewed by Turner and Malloy, presenting extensive tables, and graphs to calculate the economic thickness for large number of parameters. These parameters include combinations of pipe sizes, cost, conductivity, and temperature differences. In addition, the annual operation hours can be a critical parameter in determining the cost-effective insulation thickness. The economic problem is formulated in a general way for a system of n pipes transporting liquids at temperatures different from the environment. Each pipeline j, of length l and outer radius a_j is insulated by m_j composite layers of different insulation materials, as shown in **Fig. 1.2**.

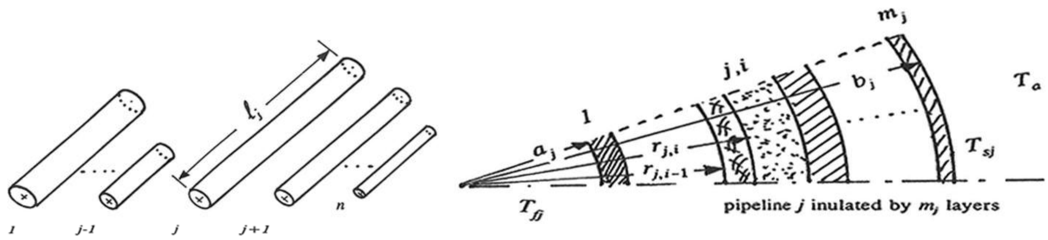


Fig.1.2. A system of *n* pipelines with composite insulation

The total cost $Z = f\,C_i + C_e = \phi(r_{ji}, k_{ji}, l_j, \Delta T_j, h_{fj}, h_a)$ **[3]**
where f is the fixed charges rate including, interest, and depreciation, C_i is cost of insulation, C_e is cost of energy loss.
N.K. Nath, K. Mandal, A. K. Singh, B. Basu, C. Bhanu, S. Kumar and A. Ghosh **[4]** have found that proper control of process parameters during LF processing of liquid steel is essential. They report development of a model based advisory system, called ladle furnace on-line reckoner (LFOR), for the prediction and control of temperature and composition of steel in a LF. The thermal and chemistry models employed in the LFOR system are based on simplified physics, material and heat balance, and statistical analysis of plant data. The performance of the LFOR system was analyzed and validated with data taken over 100 heats and was noted to be satisfactory.
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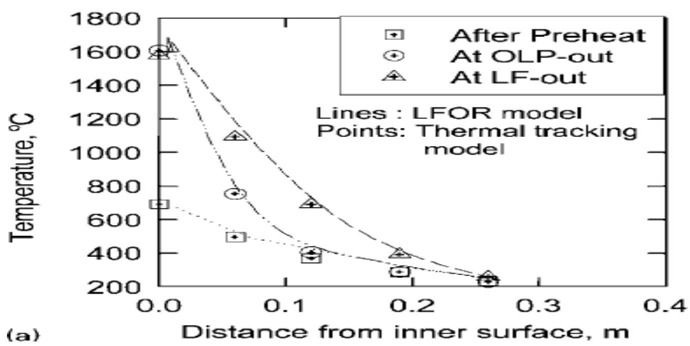

Fig.1.3. Change in ladle refractory temperature profile during secondary steelmaking

The parameters important for the thermal model can be classified as:
(i) Heat loss to refractory lining.
(ii) Heat loss due to holding and purging.
(iii) Heat gain due to arcing.
(iv) Heat effects of additions.
Temperature drop due to heat loss during the heating of the refractory can be calculated from the change in refractory temperature profile with time. For this a one dimensional transient heat transfer equation for the side wall and bottom wall was solved with the following assumptions:
Initial condition: t=0; $T_{wall} = T_{Preheat}$
Boundary condition: t=t; $T_{wall} = T_{Liquid\ steel}$

$$\rho C p \frac{dT}{dt} = h(T_{surf} - T_{\infty})$$

Heat loss to the refractory is very high initially and then gradually decreases to a more or less steady value. The sidewall thickness gradually decreases with ladle life as a result of refractory loss during the steel making process. This was taken into consideration by analyzing data on wall thickness. J. Carroll **[5],** S. Chakraborty and Y. Sahai **[6]** considered the problem of temperature stratification in a steelmaking ladle. There are three distinct zones in the flow, the wall boundary layer, the bottom stagnation zone and the central plug flow. The predictions of this model indicate the ladle can be divided into three regions. Firstly, a downward flowing boundary layer forms near the ladle wall. Secondly, a large upward flow zone forms over the rest of the ladle. Thirdly, a relatively quiescent zone forms in the base of the ladle. This zonal system is shown in **Fig.1.3**. Heat transfer in this zone is dominated by convection. Zone 3 is dominated by conductive heat loss to the ladle base. This zone is quiescent and stable due to the positive thermal expansion coefficient of molten steel. Heat transfer is essentially one dimensional.

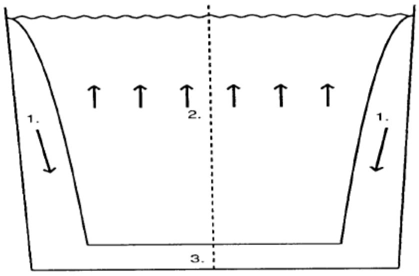

Fig.1.4. Zones of flow predicted to form in a ladle under natural convection

Dr. E. G. Hoel, C. M. Ecob and D. S. White **[7]** consider the amounts of energy that is lost from liquid iron during typical foundry operations and looked at some preventive measures as well as the benefits of more effective heat conservation in liquid iron. During processing liquid iron in ladles and holders, there will be a continuous reduction of temperature due to heat losses from conduction and radiation. In order to keep a usable pouring temperature into the mould, these heat losses must be compensated for by excess tapping temperatures at the furnace. This in turn leads to increased cost of heating the iron, as well as higher alloy consumption and refractory wear. By means of effective heat conservation, the losses and the consequences can be minimized and thereby reduce the overall cost of produced iron. The heat losses comprise conduction heat transfer through refractory linings and heat radiation from hot surfaces, as presented in more details in the following section for the ladle shown in **Fig. 1.4.**

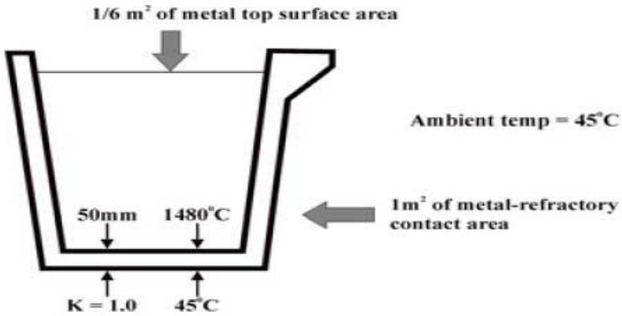

Fig.1.5. Heat Conduction through a single component wall

Conduction heat transfer is governed by Fourier's law of conduction:

$$q=-k\frac{dT}{dx} = -k\frac{T_3-T_1}{L} = k\frac{T_1-T_3}{L}$$

where Q is the heat transfer per unit area (W/m^2), k the thermal conductivity (W/m^{0}K), T_1 the temperature of the hot surface (K), T_3 the temperature of the cold surface (K), and L the refractory thickness (m). The quantity is negative because heat transfer is contrary to the direction of the heat gradient. Thermal conductivity varies between different refractory materials, and with temperature, for multiple component linings case, the heat transfer can be stated as follows:

$$q = \frac{T_1 - T_3}{\frac{L_1}{k_1} + \frac{L_2}{k_2}}$$

where k_1 is the conductivity and L_1 the thickness of material 1, etc.

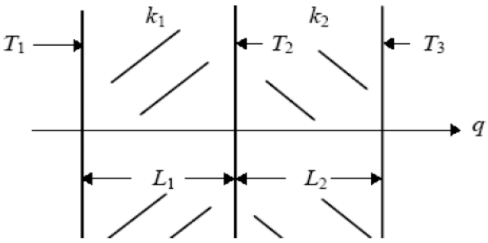

Fig.1.6. Heat conduction through a multiple component wall

2. THE LADLE

Ladle is a container extensively used in the continuous casting cycle to transport molten steel from the furnace to the casting machine. Ladles are designed to be heat insulated, apart from being heat resistant and strong.. Proper heat insulation is required so that the molten steel contained in the ladle remains at a proper temperature in different capacities. A general construction of a typical ladle of 3.2 m height and 3.5 m diameter is shown in **Fig.2.1 [8]**

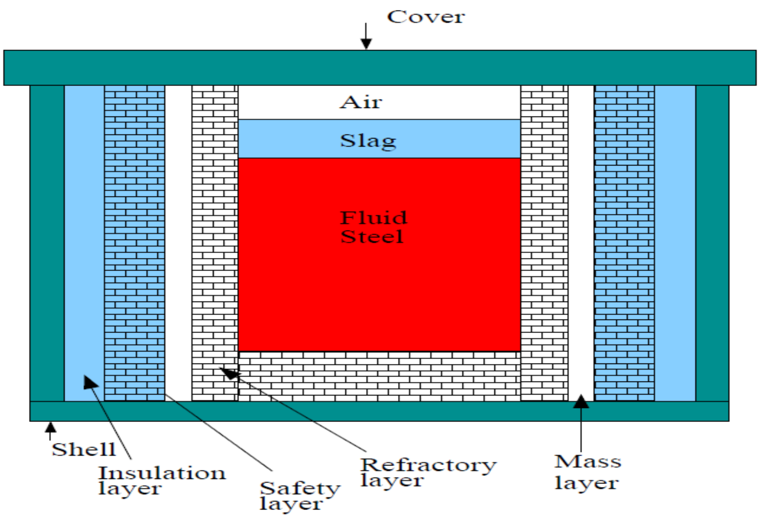

Fig.2.1. Constructional details of a typical ladle **[8]**

The ladle structure is multilayered because of the fact that a ladle should be strong and heat insulated. The inner face of the ladle is built from specialized refractory bricks. These bricks are resistant to high temperature, thus making it possible for the ladle to hold molten steel. Two types of bricks are used to construct the inner surface viz. a type of brick which interacts with the liquid steel while the other type is exposed to the slag layer above the molten steel. A mass layer is also added to the brick layer which is followed by a safety layer and an insulation layer covered by a steel shell. All these layers altogether making the ladle wall about 0.3 meters thick to withstand high temperature. A lid is used to cover the top of the ladle**[9].**

2.1. REFRACTORY MATERIALS

Refractories are heat resistant materials used in almost all processes involving high temperatures and/or corrosive environment. These are typically used to insulate and protect industrial furnaces and vessels due to their excellent resistance to heat, chemical attack and mechanical damage. Any failure of refractory could result in a great loss of production time, equipment, and sometimes the product itself. The various types of refractory also influence the safe operation, energy consumption and product quality; therefore, obtaining refractory best suited to each application is of supreme importance. Refractory are inorganic, nonmetallic, porous and heterogeneous materials composed of thermally stable mineral aggregates, a binder phase and additives. The principal raw materials used in the production of refractory are: the oxides of silicon, aluminum, magnesium, calcium and zirconium and some non-oxide refractory contain carbides, nitrides, borides, silicates and graphite**[10].**

2.2. ECONOMIC THICKNESS OF INSULATION (ETI)

Insulation of any system means capital expenditure. Hence the most important factor in any insulation system is to analyze the thermal insulation with respect to cost. Hence, there is a definite economic limit to the amount of insulation, which is justified. An increased thickness is uneconomical and cannot be recovered through small heat savings. This limiting value is termed as economic thickness of insulation. An illustrative case is given in **Fig.2.2**. This shows that thickness for a given set of circumstances results in the lowest overall cost of insulation and heat loss combined over a given period of time. The insulation thickness for which the total cost is minimum is termed as economic thickness. The curve representing the total cost reduces initially and after reaching the economic thickness corresponding to the minimum cost, it increases**[11].**

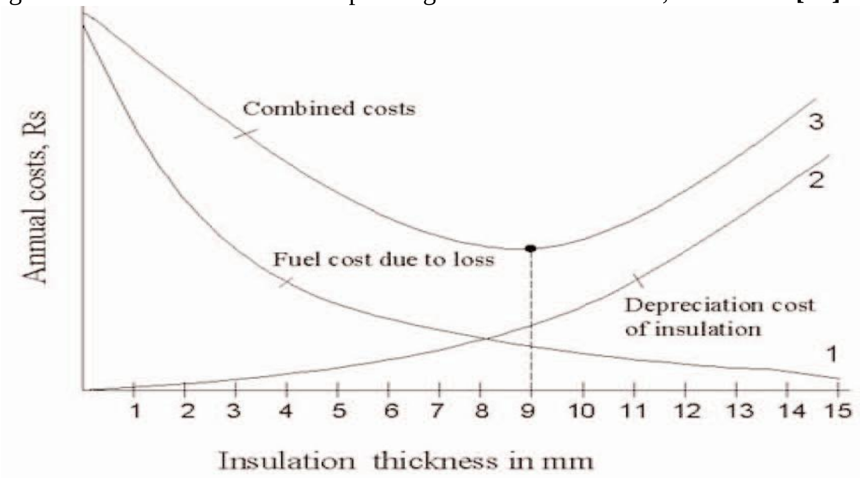

Fig.2.2.Economic Thickness of Insulation**[11]**

The wall of a casting ladle represents a multilayer thermal resistor consisting of:
(a) A working refractory lining whose thickness varies, depending on the stage of operation of the ladle and the properties of its design, from 80 to 400 mm;
(b) A buffer fill in the form of a refractory powder layer of thickness from 5 to 20 mm;
(c) A reinforcing lining of alumino-silicate composition, usually from normal chamotte brick, the thickness of whose layer is 115 mm for the wall and 130 mm for the bottom;
(d) A heat insulator from alumino-silicate fibrous articles of thickness from 10 to 30 mm; in our specific case, the heat insulation layer thickness was 20 mm for all parts;

2.3.REQUIREMENTS OF RIGHT REFRACTORY

The general requirements of a refractory material can be summed up as:

1) It should have ability to withstand high temperatures and trap heat within a limited area like a furnace;
2) It should have ability to withstand action of molten metal , hot gasses and slag erosion etc;
3) It should have ability to withstand load at service conditions;
4) It should have ability to resist contamination of the material with which it comes into contact;
5) It should have ability to maintain sufficient dimensional stability at high temperatures and after/during repeated thermal cycling;
6) It should have ability to conserve heat. **[12]**

2.4.SOME IMPORTANT LADLE REFRACTORIES

Magnesia

Modern high-purity magnesia are produced in well controlled processes. The principal sources of magnesia are brines (often deep well type) and seawater. Magnesium hydroxide, Mg(OH)2, is precipitated from these sources by reaction with calcined dolomite or limestone; one source uses a novel reactor process. Minimizing the total impurities content in magnesias is quite important because impurities affect refractoriness and performance.

Dolomite

The natural double carbonate dolomite (CaCO3 MgCO3) can be converted to refractory dolomite (CaO+MgO) by high temperature firing. A limited number of dolomite deposits exist in the world with satisfactory uniformity, purity, and calcining behavior to be processed into high purity, refractory dolomite at a reasonable cost. High purity dolomite is greater than 97% CaO + MgO and 0.5–3% impurities. Dolomite has excellent refractoriness and is thermodynamically very stable in contact with steel or steelmaking slags

Silicon Carbide

Commercial silicon carbide (SiC) used as a refractory raw material is manufactured by abrasive grain producers in electric furnaces from a mixture of coke and silica sand. The finished material is extremely hard (9.1 MOH's scale) with high thermal conductivity and good strength at elevated temperature ,as well as very good resistance to thermal shock. The material is serviceable at 1535–1650°C (2800–3000°F) for many applications.

Zircon/Zirconia

Zircon, or zirconium silicate (ZrO2•SiO2), is a naturally occurring raw material having excellent refractoriness. Specific gravity (4.5–4.6 g/cm3) is unusually high compared to most refractory materials. Zircon usually is found with other heavy mineral sands, most notably titania minerals. The refractory industry has been a major growth area for zirconia. The relatively high melting point of baddeleyite, along with superior resistance to corrosion and erosion, make zirconia an ideal component for several refractory systems. Zirconia in the natural state occurs in the monoclinic crystal phase.

Bauxite

Bauxite in the crude state is a naturally occurring group of minerals composed primarily of either gibbsite (Al2O3•3H2O), diaspore, or boehmite [AlO(OH)], and various types of accessory clays. Crude bauxite is converted to the minerals corundum (Al2O3) and mullite (3Al2O3•2SiO2) — both very refractory components.Important features of bauxites are maximum alumina values (85% or more desired), maximum bulk specific gravity, and minimum impurities such as iron oxide, titania, alkalies (Na2O,K2O and Li2O) and alkaline earths (CaO and MgO).

Carbon Group

Modern refractories use various graphite forms in combination with oxides to impart special properties. Graphites are used in refractories in order to reduce the wetting characteristics of the refractory material with respect to slag corrosion and to increase the thermal conductivity which will result in better thermal shock resistance. In oxide-carbon refractories, the carbon content may range anywhere from as low as 4–5% up to as high as 30–35%. **[12]**

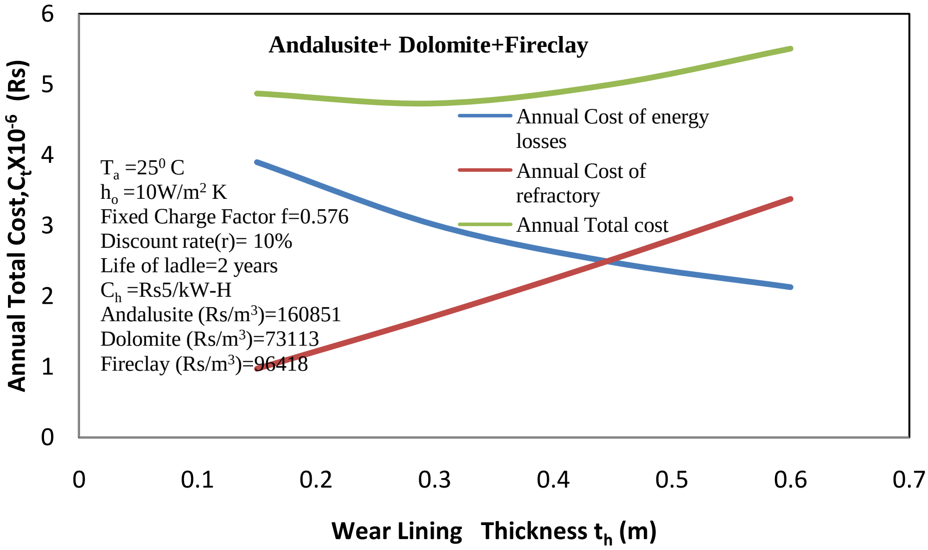

Fig.2.3. Annual Total Cost (C_t) v/s Wear Lining Thickness (t_h)**[13]**

Fig.2.3, Fig.2.4 show similar plots for the total annual costs of the system for other combinations as mentioned above. It can be seen that the cost parameters are functions of combinations used and in all the typical cases, a minima is the value of total annual cost**[13].**

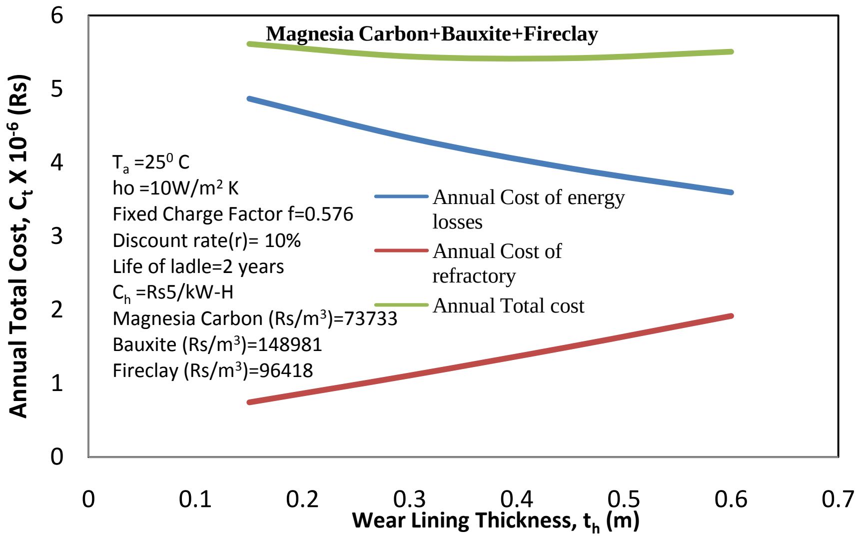

Fig.2.4 Annual Total Cost (C_t) v/s Wear Lining Thickness (t_h) **[13]**

3. STRESS-STRAIN BEHAVIOR

When a refractory is subjected to a mechanical load, it will compress. This behavior may be quantified by the following equation:

$$\varepsilon = \sigma / E \tag{3.1}$$

where: ε = strain (dimensionless),
σ = stress psi (MPa),
E = Modulus of elasticity, psi (MPa).

Strain is equal to the amount of compression divided by the original length.

$$\varepsilon = \Delta L / L \tag{3.2}$$

Stress is the force applied per unit area.

$$\sigma = F/A \tag{3.3}$$

The modulus of elasticity, or Young's Modulus, of a refractory is constant for a given material and temperature. The stress-strain behavior of a refractory material is determined by a method which is similar to that used to measure hot crushing strength. A cylindrical sample is heated uniformly to the test temperature and compressed using a mechanical testing machine. While loading the sample, the change in its height is monitored by an electrical transducer which is connected by sapphire sensing rods with the top and bottom of the sample. The data are used to create a stress versus strain curve**[12].**

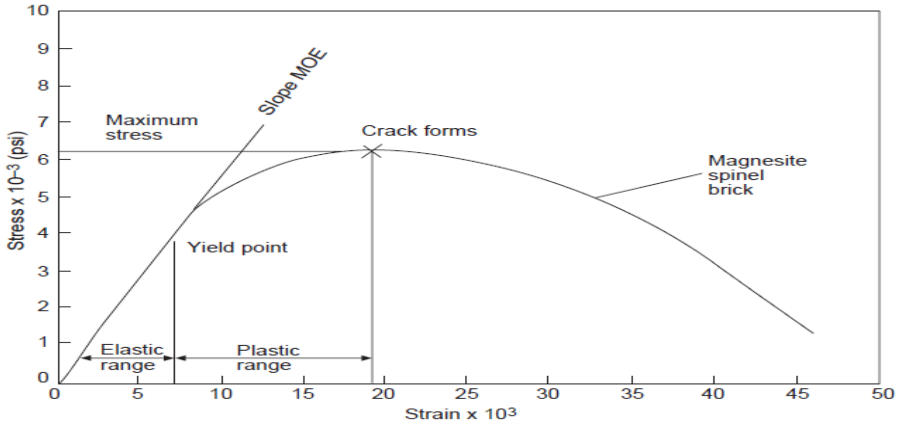

Fig. 3.1. Stress-Strain curve for magnesite-spinel brick.**[12]**

4. CONCLUSIONS

In this work, different types of refractory comprising of permanent, safety and wear lining have been studied for reducing the heat loss from the ladle furnace. Thermal and economic performance study have been done to determine energy losses resulting from the ladle as a result of heat transfer from molten steel inside the ladle and the ambient environment outside the ladle. For different refractory combination the total heat loss from the refractory wall has been considered. Following conclusions are made on the basis of above study:

1. Structure of the refractory, expressed in this case as combinations of various materials to constitute permanent, safety and wear lining has been formed to play a major role in determining the suitable refractory for the ladle. Optimum thickness of the wear lining has been found to be a strong function of economic parameters that affect the total heat loss. An increase in unit energy cost and a higher cost of refractory heavily affect the plant production capacity.
2. Variation of material results in substantial changes in optimum total annual cost values but the value of optimum wear lining thickness is not affected by these variations.
3. Advance materials should be used to withstand thermal stress and erosion.

REFERENCES

[1]. Vasile Putan, University Politehnica Timisoara, Faculty of Engineering of Hunedoara of Romania.

[2]. Heat losses from ladles during teemingby R. C. Urquhart, M.Eng. (McGiII), Ph.D. (Visitor)R. I. L. Guthrie, B.Sc. (Eng.) (London), A.R.S.M., Ph.D., D.I.C. (Visitor), and D. D. Howat, B.Sc. (Glas.), Ph.D. (Fellow)

[3]. Optimization of Multilayer Thermal Insulation for Pipelines, G. M. Zaki and A. M. Al-Turki, Mechanical Engineering Department, Thermal, College of Engineering, King Abdulaziz University,P.O. Box 9027, Jeddah 21413, Saudi Arabia

[4]. N. K. Nath, K. Mandal, A. K. Singh, B. Basu, C. Bhanu, S. Kumar, and A. Ghosh, ―Ladle furnace on-line reckoner for prediction and control of steel temperature and composition, Ironmaking and Steelmaking, vol. 33, no. 2, pp. 140–150, 2006.

[5]. J.Carroll, "A composite integration scheme for the numerical solution of systems of ordinary differential equations", J. Compo Appl. Math. 2S (1989), 1-13.

[6]. S. Chakraborty and Y. Sahai, "Effect of slag cover on heat loss and liquid steel flow in ladles before and during teeming to a continuous casting tundish",Metallurgical Trans. 23B (1992), 135-151.

[7]. Dr. E. G. Hoel, C. M. Ecob and D. S. White; Elkem Foundry Products,Reviewed 2005-07-10

[8]. Saving Energy in ladle metallurgy Dalibor Jancar ArcelorMittal Ostrava a.s., Vratimovská 689, 707 02 Ostrava,

[9]. P. R. Austin, S. L. O'Rourke, Q. L. He, and A. J. Rex, ―Thermal modelling of steel ladles,‖ in 1992 Steelmaking Conference Proceedings, 1992, pp. 317–323.

[10]. Stainless Steel Refining Richard J. Choulet, Consultant to Praxair (Presented at AISE Seminar on June 5, 1997, in Detroit

[11]. Hata K., Takeuchi Y., Shiotsu M. and Sakurai A., 1999, Natural convection heat transfer from a horizontal cylinder in liquid sodium Part 1: Experimental results, Nuclear Engineering and Design, 193, 105-118

[12]. Steel Plant Refractories,D.H. Hubble, Chief Refractory Engineer, U.S. Steel Corp. (Retired)

[13]. Dashrath Singh Kathait, Virendra Singh Rana, Arun Negi ,Economic Optimization Of Ladle Furnace RefractoryLining; Proceedings of 20th IRF International Conference, 1st March 2015, Chennai, India,