Influencing Factors on Premature Fracture of Cast Iron Support of Electric Motor in Aluminium Rolling Line

F Preda*, I Riposan† and S Stan†
1 Materials Processing & Ecometallurgy, Politehnica University of Bucharest, 313, Independentei Spl., 6th District, 060042 Bucharest, Romania

*E-mail: preda.florin89@yahoo.com

Abstract. There is a limited increase in the temperature of the cast iron supports during rolling (up to 30...50°C), but there is a wide range of vibration level (2.6 - 4.4 mm/s) representing 58-98% (75-80% as medium values) from the maximum admitted level (4.5 mm/s, ISO 10816). The maximum level of vibration is identified in the area where a fan is installed to cool the electric motor. In all electric motor types it appears a difference between several measurements, which highlights the appearance of various conditions in the rolling process, or in the quality of the cast iron support. The fracture of the support takes place predominantly in the area of fixing it with a screw. The cracks connect firstly the areas with casting defects (inclusions, pinholes, shrinkage and micro-shrinkages), but also coarse graphite particles (Kish or Type C- ASTM, spiky graphite) or undercooled graphite morphologies (Type-D ASTM). Lamellar graphite cast iron (traditionally used in this domain) are characterized by a low level of fracture resistance but high vibration damping capacity due to which it is necessary to make parts without casting defects and with a controlled graphite phase (high amount of graphite, graphite Type-A ASTM, without undercooled graphite), usually obtained through high performance inoculation [1,2].

1. Introduction
The objective of this study case is represented by the analysis of the causes leading to the premature fracture of the cast iron support of the electric motor from the rolling-line components and the rolling bridges in the aluminium industry and identifying ways to prevent this fracture.

The rolling line consists of three important machines, the principal machine being the hot rolling which has the role to processing by plastic deformation using two work cylinders and two reversible support cylinders. They reduce the size of the aluminium products in the direction of pressing from raw thickness of 530 mm until 7 mm.

The next two components of the rolling-line are two cutting to length machines located at the line extremities, namely: one cutting to length machine of 3430 kN (F350) which cuts the material up to a maximum thickness 40 mm and one cutting to length machine of 7355 kN (F750) which cuts the material with a minimum thickness of 40 mm up to 180 mm. Regarding the material transport from the hot rolling to the cutting machine and back, it is used a transporting roller including an electric motor type : TML 100A B35, ASU - IM 3001, B30 – KL 160 with a power of 11 kW.

The rolling bridges have the role of lifting and carrying in the horizontal direction the load (coils, rolling cylinders, plates, mechanical parts with oversize) and have a maximum lifting weight of 79 kN, 118 kN, 618 kN or 1177 kN. The rolling bridges have the following components parts:
a) A crane trolley, which is composed of the lifting mechanism of load and the movement mechanism of the crane trolley which are both made from an electric action motor type: ASU 225M-8, CEI 34-1 or K500 with a power of 25kW, a coupling, an industrial gear reducer and an electro-brake;

b) The movement mechanism of the bridge which is composed of an action group at the end of the line made of an electric action motor type: TML 100A B25, CEI 34-1, K500 or ASU 200L-8 with a power of 35kW, a coupling, a gear reducer and a electro-brake which drives the rolling wheels.

The electric motor includes a cast iron support (Figure 1) with the role of fixing the motor in the transporting roller and rolling bridges area. Due to the mechanical shocks and the continuous vibrations during the use, these pieces-parts could present fractures prematurely and after that to block the transporting roller and damage the rolling material. If a motor does not work, the rolling bridge cannot be used, this delaying the production process.

![Figure 1. Iron cast support from the electric motor ensemble.](image)

2. Experimental Procedure
In this study there are analyzed 20 grey iron castings (with lamellar graphite) used as supports for the electric motor from the rolling assembly component (Figure 2), and which have been subjected to vibrations and mechanical shocks in different circumstances.

![Figure 2. General scheme of the ensemble and vibration measurement points (P1, P2, P3): (a) motor scheme mounted on the crane bridge; (b) motor scheme mounted at the transporting roller.](image)

There is a number of 6 cast iron supports at 3 motors from the transport roller that are positioned in 3 points on the rolling line namely: one is positioned near the cutting to length machine of F350, one near rolling and one near the cutting to length machine of F750. The last one is placed as close as possible of the main machine of the rolling line because the vibrations make their presence felt.

The remaining 14 supporting cast iron parts from 7 engines are analyzed in the component of the rolling bridges besides the vibration chock that comes from the impact of the bridges at the end of the line and also the crane trolley. It is also taken into consideration the possibility of thermal demand because of comparing to the ambient temperature (for example, in winter can be -5°C and in summer up to 30°C) in some cases will be added also the heat generated by electric furnace.
Table 1. Parameters of the experiment conditions.

| Electric Motor Type | Motor work area | Tested Supports | Moment of vibration measurement |
|---------------------|-----------------|-----------------|---------------------------------|
| TML 100A B35        | Transporting roller (rolling area) | 2               | When transporting raw material, during the rolling process; when transporting thin but long material (coil) |
| ASU - IM 3001       | Transporting roller (F350)          | 2               | When transporting the material before to be cut, after cutting and during the cutting process |
| B30 – KL 160        | Transporting roller (F750)          | 2               | When transporting the material before to be cut, after cutting process, during cutting and when the scrap drops |
| ASU 225M-8          | Rolling bridges (travel load)       | 2               | Without load, with the load allowed 12t, during load lifting |
| CEI 34-1            | Rolling bridges (travel crane trolley)| 2           | During transport with the load allowed 12t, without load |
| K500                | Rolling bridges 1177kN (travel crane bridge) | 2       | During transport with the load allowed 12t, without load, during travel the crane trolley |
| TML 100A B25        | Rolling bridges 1177kN (travel load) | 2       | Without load, with load of 12t, during load lifting |
| ASU 200L-8          | Rolling bridges 1177kN (travel crane trolley) | 2 | When transporting with the load of 12t, without load |
| CEI 32-1            | Rolling bridges 1177kN (travel crane bridge) | 2   | When transporting with the load of 12t, without load, during to travel the crane trolley |
| ASU 200L-8          | Rolling bridges 1177kN (travel crane bridge) | 2   | When transporting the work cylinders (98t) for change |

The equipments used to realize this study case are: a) SKF microlog analyser used to measure and analyze the vibrations of the motor and also its temperature; b) a digital thermometer with laser Trotec for measurement of temperature; c) microscopes Olympus and 3D Hirox for performing the structural analyze to the cast iron support, broken premature.

In Table 1 is presented the analysis procedure for 20 cast iron supports, the type of motor and the moments of vibrations measurement.

3. Results and Discussion

3.1. Variation of the temperature

Figure 3 includes the measured value regarding to temperature in the case of the TML 100A B35 motor (Table 1), mounted on the transporting roller (rolling area). It could be observed an increase and a decrease of the temperature of the cast iron support of the electric motor, during its using: in the moment when the material for rolling (to 500°C) is transported on the rollers; when it is rolled; where it is transported to cutting. The time for the entire cycle of rolling is around 20min/rolled product.
Figure 3. Temperature variation of the electric motor during the rolling process (the motor TML 100A B35, Tab. 1) (A) - start of measurement; (B) - transport of material on the roller; (C) - after the 10 pass of rolling; (D) - after the last pass of rolling; (E) - go to the cutting.

It is appreciated that the heating of the electric motor ensemble is limited (30...50°C), and as a result, the cast iron support shouldn’t be affected concerning its behaviour in the exploitation.

3.2. Vibration level evaluation

Vibrations are measured throughout the rolling process from putting the aluminium product on the transporting rollers to the last rolling pass. Figure 4 illustrates a typical evolution of the level of vibrations measured in the case of the motor TML 100A B35 (transporting roller).

Figure 4. Typical example of the vibration level of the electric motor (P1, P2, P3 - measurement points, see Figure 2).
The Table 2 and the Figures 5 and 6 include the level of vibrations measured in the case of the 20 tests performed, two for each motor considered. P1, P2 and P3 represent the vibration measurement points of the electric motor assembly, highlighted in Figure 2.

The measurements performed showed that there is a wide range of framing of vibration level of electric motors, respectively 2.6 - 4.4 mm/s. At the same type of motor, it appears differences, sometimes important, between two measurements, which highlights the appearance of various conditions in the rolling process. There are not obviously different behaviours between the electric motors used to transporting roller and respectively the rolling lines of aluminium products.

Regarding the measuring points, the maximum level vibration is at P1, in the area where a fan for cooling the electric motor is mounted. In case of this fan has been turned off, as at the motor CEI 34-1 (see Table 2), the measured value of the vibrations decreased substantially. Then follows the measuring point P3, and, at the lowest level, the measuring point P2.

Table 2. The measured values of the electric motor vibrations.

| Motor Electric Position | Electric motor Type (are working) | Measured value of vibrations, mm/s, in points: |
|-------------------------|----------------------------------|-----------------------------------------------|
|                         | P1     | P2     | P3     |
| Transporting Roller     |        |        |        |
| TML 100A B35 (rolling)  | 3.8    | 4      | 4.1    |
| ASU - IM 3001 (F350)    | 3.5    | 3.0    | 3.4    |
| B30 – KL 160 (F750)     | 3.8    | 3.6    | 3.2    |
| Average                 | 3.63   | 3.43   | 3.65   |
| Rolling Bridges         |        |        |        |
| ASU 225M-8 (travel load)| 3.7    | 3.5    | 3.6    |
| CEI 34-1* (travel crane trolley) | 3.2 | 2.8 | 3.3 |
| K500 - 1177kN (travel crane bridge) | 4.4 | 4.0 | 4.3 |
| TML 100A B25 - 1177kN (travel load) | 4.0 | 3.8 | 3.9 |
| ASU 200L-8 - 1177kN (travel crane trolley) | 3.5 | 3.4 | 3.3 |
| CEI 32-1 - 1177kN (travel crane bridge) | 4.2 | 3.8 | 3.9 |
| ASU 200L-8 - 1177kN (travel crane bridge) | 3.8 | 3.6 | 3.2 |
| Average                 | 3.67   | 3.39   | 3.54   |
| General Range           |        |        |        |
| General Average         | 3.66   | 3.40   | 3.58   |

* - without fan (without electric motor cooling)
Figure 5. The vibration level of the electric motors that operate in the presented conditions in Table 1. (P1, P2 and P3 – points of measuring, Figure 2) (2 measurements for each type of electric motor).

Figure 6. Framing range and average vibration values, in the measurement points P1, P2 and P3 (see Figure 2).

In accordance with the international standard ISO 10816, the maximum allowed value of the vibration level of electric motor is 4.5 mm/s. In the analyzed case, the vibration level represents 58 - 98% of the maximum accepted level, respectively at level 75-80% of their environments. It is appreciated that in the analyzed case, this level is high, and that measures are needed to reduce vibration. In this case, the iron cast support of electric motor can play an important role.

In case of cast iron parts, graphite has a positive important role in vibration damping, favouring the dissipation of the energy appeared such a request. As a result, the amount of graphite, the graphite morphology and the degree of compactness of the graphite particles play an important role. Suggestive in this sense are the data presented in Figure 7, obtained by processing the data from the paper [3] that highlight the damping capacity of the cast iron with lamellar graphite (grey cast iron), graphite compact/vermicular (compacted graphite cast iron) and with nodular graphite (ductile iron). In this
case, damping capacity is expressed by cyclic toughness, as a ratio between hysteresis curve area (\(\mathcal{W}\)) and area under force-strain curve (\(W\)). The larger it is the higher value is, with that damping capacity is bigger. In case of lamellar graphite (LG) cast iron, the chemical composition is varied to a large extent expressed by the equivalent carbon value (CE = 3.5 - 5\%). For compacted graphite cast iron and nodular graphite cast iron, chemical composition was used of the typical values for each cast iron type, respectively CE = 4.2 - 4.5\%.

**Figure 7.** Tensile strength (a) and damping capacity (b), (c) of cast irons with lamellar graphite (LG), compacted/vermicular graphite (CG) and nodular graphite (NG).

Increasing the value of the equivalent carbon (CE) means the transition from the hypo-eutectic domain, through the eutectic domain up to the hyper-eutectic domain, action accompanied by the increase significant amount of graphite in the cast iron structure. Consequently, tensile strength (Rm) decreases significantly in the case of lamellar graphite cast iron (Figure 7 a)). Intermediate compacting of graphite until to morphology of compacted graphite (CG) substantially increases the tensile strength, with the maximum value reached the maximum degree of compactness of the graphite.
respectively the nodular graphite (NG), despite the fact that these castings are usually characterized by high values of carbon equivalent.

A variation into reverse shall be recorded in damping capacity (Figure 7 b)): increasing the amount of graphite with the increase of the equivalent carbon leads to the increase of the vibration damping capacity to castings iron pieces. The graphite compacting decreases the vibration damping capacity, which is why in case compacted graphite (CG) and especially nodular graphite (NG), lower values of this parameter are reached, although these cast irons have a large amount of graphite.

Figure 7 c) illustrates the strong connection between damping capacity and tensile strength, with graphite positioning as morphology (LG, CG, NG). It is found that in the case of compacted graphite cast iron (with a large amount of graphite in structure), the vibration damping capacity is of the same order of size with that one of lamellar graphite cast iron, with a low carbon saturation degree (small amount of graphite), respectively high tensile strength.

It is known that in the case of grey cast irons, used in the automotive industry, in production for engine block, lamellar graphite morphology is also important: the presence of undercooled graphite (D-type Graphite, ASTM) determines the decrease not only of tensile strength but also of the damping capacity. As a result, metallurgical inoculation treatment of grey cast irons appears to be useful for achieving simultaneous improvement of tensile strength and damping capacity, both of them very important to avoid premature fracture of the cast iron support of electric motors.

3.3. Characterization of fracture areas of cast iron supports

It is identified the area where it was produced the fracture of the grey cast iron (lamellar graphite) support of the electric motor (Figure 1), mounted in the conditions presented in Figure 8. Several broken parts were analyzed (Figure 9), regard the initiation and development for the cracks (Figures 10 and 11).

![Figure 8](image_url)

**Figure 8.** Identify the fracture areas of cast iron supports of an electric motor: (a) motor K500; (b) motor ASU 200L-8 (crack thickness of 18mm for motors of 35KW); (c) motor B30 – KL 160 (crack thickness of 9mm for motors of 11KW).

![Figure 9](image_url)

**Figure 9.** Example of fracture of cast iron support, for electric motor in aluminium rolling lines.
Figure 10. Evolution of the crack of the cast iron support: (a) micro-crack initiation; (b) crack development; (c) cracking before the piece fractured (Olympus Microscope analysis).

The analysis of a large number of cast iron supports, used to fixing the electric motors on the aluminium rolling line, leads to conclusion that fracture of these parts occurs predominantly in the screw area. Usually, micro-cracks are initiated on the surface of the support from contact with the screw, then developed into cracks in the mass of the cast iron part. Usually, the braking is favoured by the lack of material addition for avoiding the occurrence of defects and lack fall of pass from thin-walled to the thick-walled.

Following the route of the cracks, it is found that they unite in the first time areas with castings defects, of the type pinholes (gaps due to gases) and voids/micro-voids (gaps due to contraction phenomena). In the case of these grey cast iron pieces (lamellar graphite), it was also found that graphite morphology (type) play an important role. In this regard the coarse forms of graphite such as the type C-ASTM (specific to primary graphite, Kish graphite) as well as those specific to degenerated graphite (example Spiky graphite) favour the accelerated development of cracks. Simultaneously with the preferential development of cracks through the mentioned areas, there are not found cracks in the structural areas where appears lamellar graphite of type A-ASTM. This graphite morphology, that maximizes the achievement of maximum strength characteristics, usually includes relatively evenly distributed blades in the structure, to medium size (50 - 250 μm), uncut tips. This goal is usually through inoculation treatment, based on treating liquid cast iron with active substances, including inoculating elements [4]. These elements are able to positive influence quality of graphitization sites and thereby reducing the degree of undercooling at the eutectic solidification, necessary condition to form Type-A graphite [3].

4. Conclusions
The analysis of the premature fracture of cast iron parts, used as supports for electric motors included in the rolling lines of aluminium products, in terms of the use of these motors in industrial conditions, leads to the following conclusions:

a) It is a limited increase in the temperature of these parts during rolling (up to 30 ....50°C), which should not particularly affect their behaviour in plant conditions.

b) The performed measurements highlight the existence of a wide range of framing of the vibration level of electric motors, 2.6 - 4.4 mm/s, constituting 58 - 98% (75-80% as medium values) from the maximum allowed level (4.5 mm/s, ISO 10816).

c) The vibrations level appears to be maximum in the area where a fan is installed for cooling the electric motor (obviously decreases when the fan is stopped).

d) At the same type of motor there are sometimes important differences, between several measurements, which highlights the appearance of various conditions in the rolling process, or in the quality of the cast iron support.
Figure 11. Cracking analysis before fracture using 3D Hirox Microscope: (a), depth of the beginning of the crack 18 μm); (b) the starting area of the crack in the piece of cast iron with lamellar graphite.
e) It is appreciated that the vibration level is high which means that measures are required to reduce it, including by improving the quality of cast iron support.

f) The broken of these parts takes place predominantly in the grip area with screwing the micro-cracks initiated at contact with the screw developing cracks in the mass of the cast iron piece.

g) The cracks primarily unite areas with casting defects (inclusions, pinholes, shrinkage and micro-shrinkages), but also coarse graphite particles (Kish or Type C- ASTM, spiky graphite) or undercooled graphite morphologies, such as Type-D ASTM.

h) Lamellar graphite cast irons, traditionally used in this field are characterized by low resistance of fracture level but high vibration damping, the reason which is why it is necessary to make parts without casting defects and with a controlled graphite phase (large amount of graphite, Type-A ASTM), obtained by specific metallurgical treatment, inoculation.

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5. References
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