SRM – EXTERNAL MARKS ON TUBES SURFACE*

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Abstract

Stretcher Reducing Mill (SRM) is a mill used in production of tubes. It is composed with a set 24 of stands responsible to define the final outside diameter (OD) of tubes. External appearance is critical in this process even though this requirement has no effect on mechanical properties. For this reason, an investigation of external longitudinal marks mechanism is in progress using 6 Sigma methodology. This paper is a part of the investigation with focus on the rolls and its mechanical properties. Destructive tests were performed in the rolls and compared with the project. After a detailed investigation, it was concluded that rolls were out of hardness specification and the project was poor of information. A new supplier was developed (internal market) based on the new project and all requirements were achieved as demonstrated in this paper. A monopolistic market for this product in VSB (Vallourec Soluções Tubulares do Brasil) was eliminated. Concerning the effect on the external longitudinal marks, the new rolls developed within hardness range minimized the mechanism of wear on rolls surface and consequently on tubes surface. A collateral effect has been faced, but still better than external longitudinal marks on tubes surface. The quenched and tempered rolls are more sensitive for process variation, mainly linked with cooling system and temperature of tubes (mechanical resistance for deformation). Nevertheless, a new material has been aimed focusing on reduction of rolls breakage with good tenacity and affordable cost.

Keywords: External longitudinal marks; SGI; hardness; matrix; chemical analysis.

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1 INTRODUCTION

External longitudinal marks in SRM (Stretcher Reducing Mill) are a critical defect for external quality of tubes. There are many possibilities to generate it on tubes surface and this article presents one of the possible cause. The complete study is in progress using 6 Sigma Methodology. The external longitudinal marks are represented in figure 1 and premature wear on rolls surface in figure 2:

Figure 1. External longitudinal marks on a tube surface with OD 1 ¼".

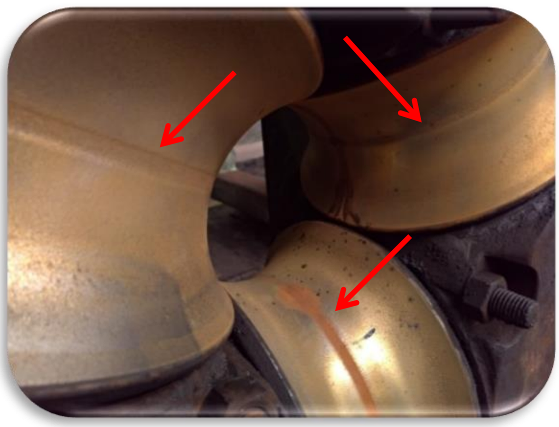

Figure 2. Representation of wear on rolls surface.

A set of maximum 24 stands works together reducing proportionally the OD size from a specific OD delivered by Continuous Mill to SRM. SRM rolls are assembled in a stand as the scheme below in figure 3:

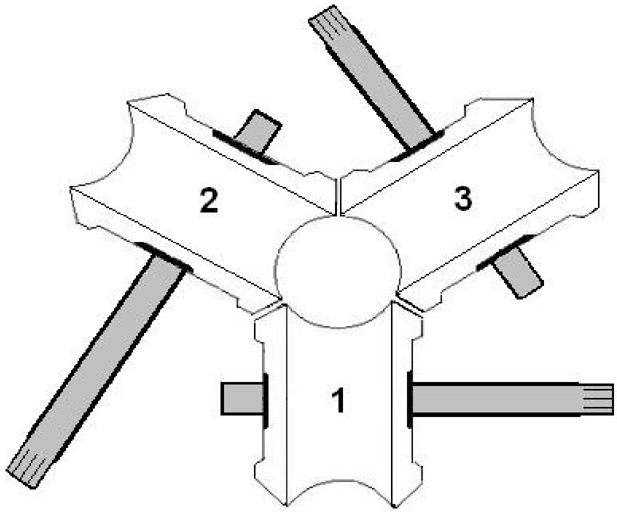

Figure 3. Sketch of three rolls disposition in a stand.

The focus is on the mechanical properties of rolls supplied by external market. A reasonable investigation of mechanical and metallurgical properties was performed in rolls that came from the main supplier (>80% of total stock).

The original project requires a SGI material (Spheroidal Graphite Iron) with 480 to 510 HV only. SGI alloyed with Cr, Ni and Mo was introduced around 1950y as an option for mills that produces Long Products [2] and practically all mills in Vallourec Group use it. The spheroidal graphite shape, also well-known as Nodular Iron, is responsible to give good mechanical properties with moderate tenacity mainly alloyed with Cr. Ni and Mo cited above.

A simple characterization was performed in some rolls that faced premature wear. Some tests were performed, such as:

- Metallography
- Hardness
- Chemical analysis

1.1 Metallurgy – basic understanding of SGI concept

There are two diagrams to represent the solidification of cast iron: Stable and metastable Fe-C diagrams.

Stable: The carbon is presented in the form of graphite, such as Gray and Spheroidal Iron.

Metastable: The carbon is mainly presented in the form of carbides, such as white cast iron.

The chemical composition defines which way the solidification may prevail. The elements such as Sn, P, Si, Al, Cu, Ni are graphite's formers whereas Mn, Cr, Mo, V are carbides' formers [1]. In figure 4 and 5 are shown the difference in Fe-C Equilibrium Diagram for each way of solidification:

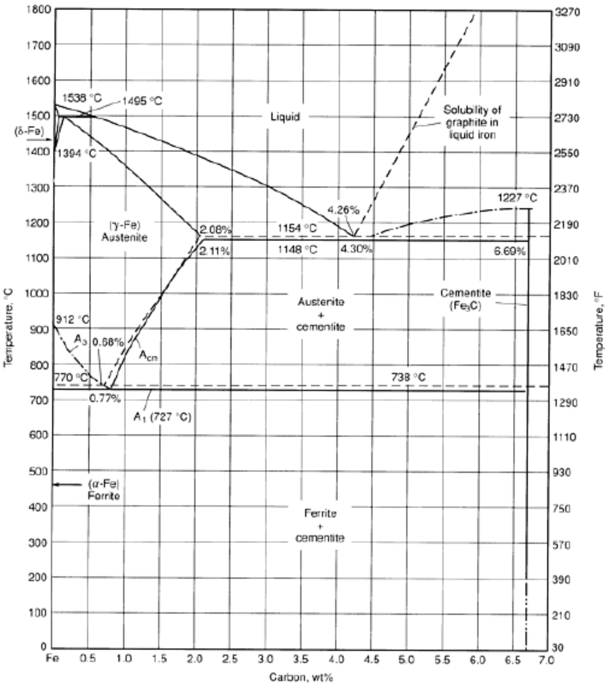

Figure 4. Iron-carbon equilibrium diagram up to 6.67 wt% of Carbon. Solid lines indicate Fe-Fe3C diagram (Metastable diagram); dashed lines indicate iron-graphite diagram (Stable diagram) [3].

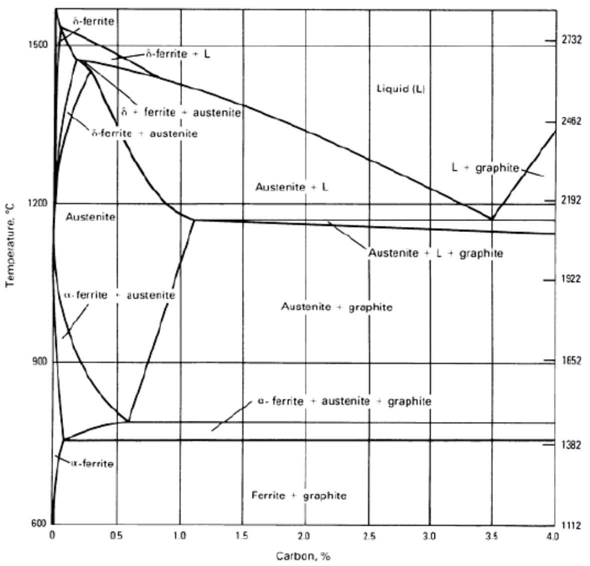

Figure 5. Iron-carbon phase diagram at 2.5% Si [4].

There is a range of temperature that graphite will precipitate naturally from the liquid. The range is the difference between Stable and Metastable transition line from liquid state to solid state in the eutectic point. In the Metastable diagram this temperature is 1.147ºC and Stable diagram is 1.153°C [5] as shown in the figure 6:

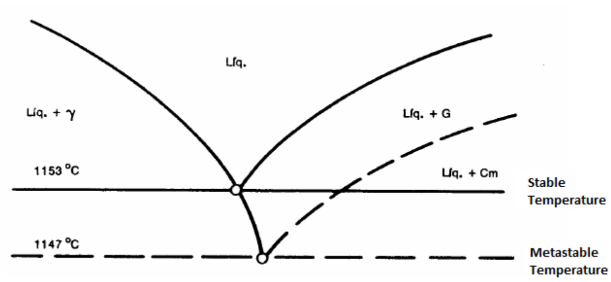

Figure 6. Overlap of both diagrams Stable and Metastable temperature close to the eutectic point [5].

The elements alloy cited previously can facilitate the opening or closing this range of temperature. If it is opener range, more graphite may precipitate and if it is closer range, more carbide may form.

Considering that the focus is on Nodular Graphite Iron, it is important to say that a specific technique is used in order to ease the precipitation of graphite. It is a process named nodularization and inoculation. In the nodularization process, an alloy with Fe-Si-Mg is used to decrease the surficial energy by reducing the oxygen and phosphorus in the liquid metal favoring the mechanism that enhances the growth of nodular graphite [6]. The inoculation process takes place after nodularization and preferentially shortly before or during pouring. It uses a mix of Fe-Si to nuclei points of solidification and increases the spheroidal graphite formation [7].

The graphite can be classified by the type and amount based on ASTM A247 [8] as demonstrated in figure 7 and 8:

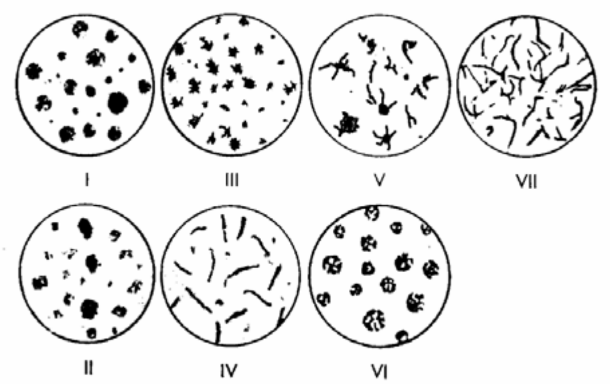

Figure 7. Type of graphite based on ASTM A 247 visual standard [8].

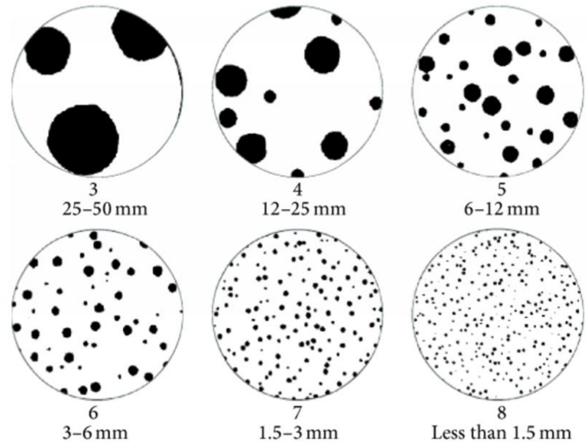

Figure 8. Class 3 to 8 for amount of graphite based on ASTM A 247 visual standard [8].

1.2 Hardness and Tenacity

The first impression when discussing about cast iron is a metal with high carbon content, high hardness, low energy absorption and fragile fracture. In fact it is the most common condition of cast iron, but it is possible to reach low hardness with reasonable energy absorption and fatigue fracture. For this reason, the cast iron with these mechanical properties is also known as Ductile Cast Iron. It is possible due to the carbon precipitation and nucleation in a spheroidal shape in a predominant ferrite matrix [3]. Depending how the carbon is dissolved in the microstructure, great elongation could be achieve (18% i.e.) [3]. Including special heat treatments such as ADI (Austempered Ductile Iron), the mechanical properties may be increased considerably with still good tenacity [9].

1.3 Chemistry for SGI

The common chemistry for SGI is based on carbon and silicon content. In cast iron, the carbon is presented not only in austenite form but also in carbide or graphite form since the carbon saturates in austenite phase with C = 2,08%.
The silicon is an important element for graphite formation. Silicon favors the decomposition of cementite into ferrite and graphite [1]. The addition of alloy elements provides different properties. For rolls applied in mills, carbides are interesting to provide wear resistance. However, net of carbides are undesirables since it could lead a premature and catastrophic failure (fragile and total rupture of the roll).

The common chemical composition for ductile iron in a ferritic matrix, based on ASM Handbook [3], is shown in table 1:

Table 1. The common chemical composition for Ductile Iron (ferritic matrix) based on Handbook

C	Si	Mn	Cr	Mo	Ni	S	P	Mg	Cu
3,6 - 3,8	1,8 - 2,8	0,15 - 1,00	0,03 - 0,07	0,01 - 0,10	0,05 - 0,20	0,002 max	0,03 max	0,03 - 0,06	0,15 - 1,00

A chemical composition for white cast iron in a martensitic matrix, based on ASTM A532-75a [10], is shown in table 2:

Table 2. Chemical composition for martensitic white cast iron based on ASTM A 532-75a. Class I, type A and designation Ni-Cr-HC

C	Si	Mn	Cr	Mo	Ni	S	P
3,0 - 3,6	0,8	1,3	1,4 - 4,0	1,0	3,3 - 5,0	0,15	0,30

The chemical composition is dependent of the microstructure. Elements such as nickel, chromium and molybdenum favor the solidification in the metastable diagram whereas the lack of these elements and more carbon and silicon content, favor the solidification by stable diagram [1].

The reference of chemical composition used in rolls at VSB is shown in table 3:

Table 3. Chemistry for rolls used at VSB.

C	Si	Mn	Cr	Mo	Ni	Mg
3,50	1,60	0,70	0,50	0,40	2,00	0,04

The chemical analysis cited above generates, in as-cast condition and no controlled cooling, a perlitic-ledeburite microstructure with nodules of graphite due to nodulatization and inoculation treatment. It is not a common microstructure for a commercial cast iron, but this chemistry is largely used in Vallourec's Mills.

2 MATERIAL AND METHODS

First of all, a characterization was carried out to verify whether the basic project requirements were achieved.
A hardness test along the cross section was performed using a Duroking 3 tons with a 10 millimeters tungsten sphere. Results were presented in Brinell (HB).
Subsequently, the microstructure was characterized in order to identify the graphite, despite of the type and amount of nodules per square millimeters. The result of a not etched microstructure was compared with ASTM A247 visual standard.
Even it is not specified, the following analysis was performed:

- matrix characterization by optical microscope;
- Micro-hardness in the matrix compounds;
- Chemical analysis.

After performing the characterization process, a new process was developed in partnership with an internal market supplier. The new development process was based on all information collected and heat treatment was added in order to achieve the required hardness and consequently improve the wear resistance.

3 RESULTS AND DISCUSSION

The results are presented as characterization phase and development phase concerning:

- Hardness (Brinell)
- Metallography for nodules classification
- Chemical analysis
- Metallography for matrix characterization
- Micro hardness (Vickers)

3.1 Characterization phase – current situation

3.1.1 Hardness (Brinell)

The hardness in a roll involved with premature wear varies from 409 HB in the surface to 363 HB in the core as demonstrated in figure 9.

Figure 9. Brinell results from the surface down to the core.

The specification requires hardness from 450HB to 480HB. The hardness measured is out of specification.

3.1.2 Metallography – Nodules classification

Despite the lack of specification for type and distribution of graphite, the result obtained was satisfactory as demonstrated in figure 10:

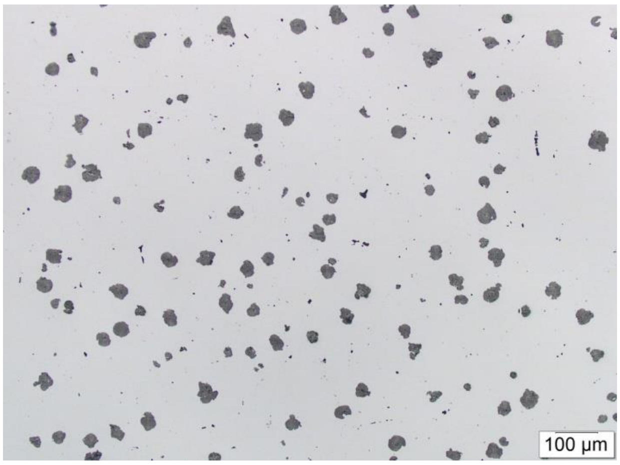

Figure 10. Graphite characterization as polished. 100x. Type II Class 6 based on ASTM A247.

3.1.3 Chemical Analysis

The chemistry was measured and the result is shown in table 4:

Table 4. Chemistry measured in the same sample

C	Si	Mn	Cr	Mo	Ni	Mg
3,52	1,73	0,77	0,38	0,55	2,13	0,03

3.1.4 Matrix

The matrix characterized is a perlitic-ledeburite structure with carbides. This matrix is not common for SGI as it is for white cast iron. In figure 11, the matrix revealed and 500x amplified is shown:

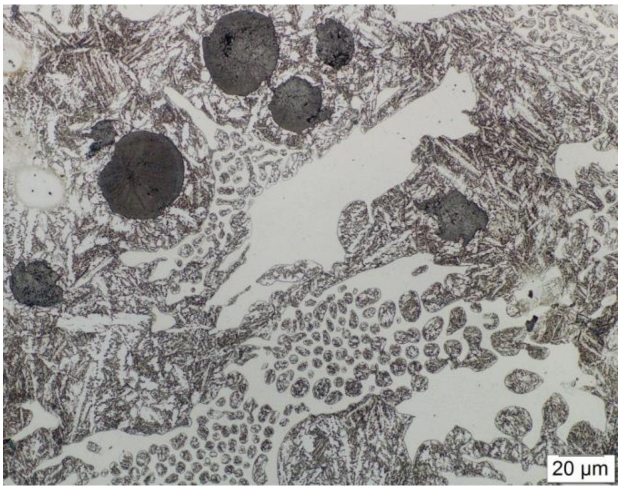

Figure11. Matrix characterization as polished and etched. 500x. Perlite and ledeburite (as-cast) with carbides.

3.1.5 Micro-hardness

For knowledge only, the micro hardness was taken in each element of the microstructure, namely: Perlite and carbide. Two different micro-hardness were identified for two different shapes of carbides. The elongated one showed a higher micro-hardness and the rounded one showed a lower micro-hardness as demonstrated if figure 12 and table 5. The spheroidal graphite has the hardness about by 30 HV as demonstrated for FERNANDES [11].

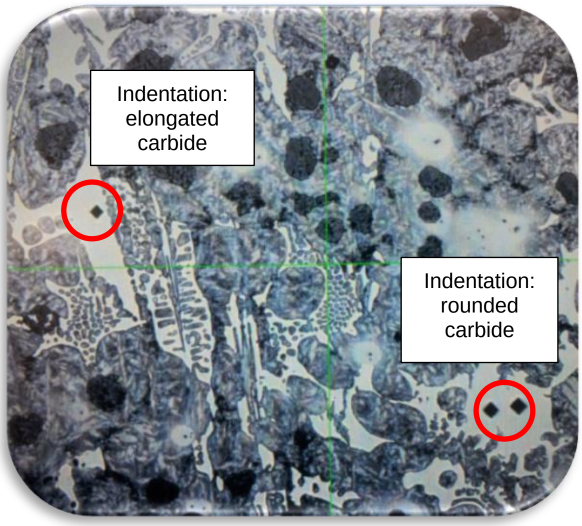

Figure 12. Matrix characterization as polished and etched. 500x. Perlite and ledeburite (as-cast) with carbides.

Table 5. Micro-hardness measured on the same sample characterization

Structure	Measure	Measure	Measure	Average
Perlite	369	294	392	351
Elongated Carbide	1151	1042	1042	1078
Rounded Carbide	634	719	836	730

3.2 Development phase with a new supplier

Based on all information generated, it was decided basically to maintain the chemical composition and add a heat treatment in order to strengthen the matrix and consequently to improve the wear resistance.

The heat treatment applied was quenching and tempering following the steps below:

1st) Heat the rolls up to 860ºC and maintain in this temperature for 1 hour/inch
2nd) Cool in heated oil down to 100ºC
3rd) Temper in 300ºC for 2 hours/inch
4th) Cool at room temperature

3.2.1 Hardness (Brinell)

The hardness measured by Brinell technique showed a 475 HB in all points along the cross section of the quenched and tempered roll, as demonstrated in figure 13.

Figure 13. Brinell results from the surface down to the core in a quenched and tempered roll.

3.2.2 Metallography – Nodules classification

Despite of lack of specification for type and distribution, it was aimed to achieve the same type and class of graphite. However, slightly higher spheroidal graphite size was achieved, but still satisfactory as demonstrated in figure 14:

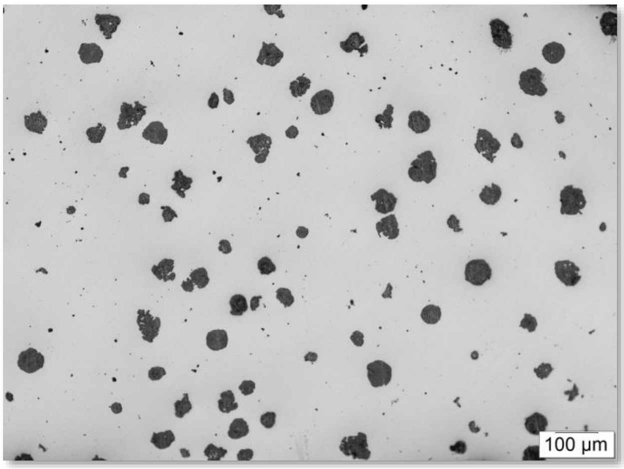

Figure 14. Graphite characterization as polished. 100x. Type II Class 5 based on ASTM A247.

3.2.3 Chemical Analysis

The chemistry was measured and the result is shown in table 6:

Table 6. Chemistry measured in a same quenched and tempered roll where hardness was taken

C	Si	Mn	Cr	Mo	Ni	Mg
3,49	1,57	0,70	0,45	0,40	1,98	0,04

3.2.4 Matrix

The matrix achieved was a refined martensite with reticulated carbides. In figure 15, the matrix 500x amplified is shown:

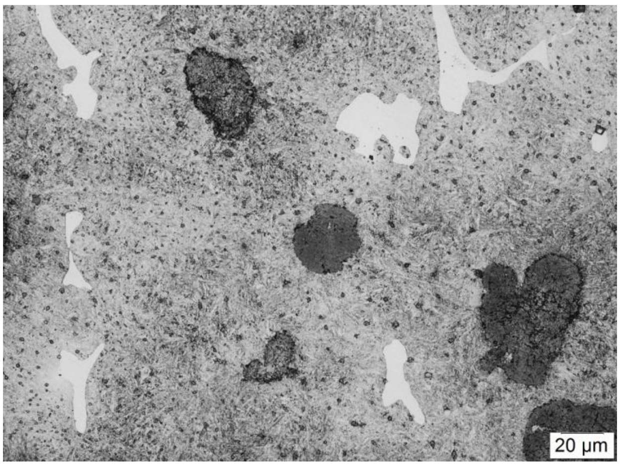

Figure 15. Matrix characterization as polished and etched. 500x. Total transformed matrix in a refined martensite with reticulated carbides.

3.2.5 Micro-hardness

For knowledge only, the micro hardness was taken in each element of the microstructure, namely martensite and carbide. The results in table 7 demonstrate no significant difference of hardness in carbides as observed in as-cast condition.

Table 7. Micro-hardness measured on the same quenched and tempered roll

Structure	Measure	Measure	Measure	Average
Martensite	725	707	731	721
Carbide	1062	1128	1225	1138

4 CONCLUSION

The hardness of rolls was improved via quenching and tempering heat treatment. After running a batch of 25 rolls with no significant catastrophic failures during its lifetime, more rolls manufactured by this process were assembled.
When a set of 24 stands was assembled in the mill with different rolls suppliers, the wear was observed in all rolls except in quenched and tempered rolls.
After a time, the number of breakage increased substantially whereas premature wear on rolls surface reduced significantly. The increase of breakage may be linked with not only quenching and tempering process developed for the rolls but also with the reduction of temperature in the re-heating furnace focusing on cost reduction.
The next step is to develop a new quality of rolls focusing on the increase of tenacity. An Austempered Ductile Iron (ADI) could be an alternative material once High Speed Steel (HSS) is an expensive alternative for this application.

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