Remarks on Some Issues of Roll Business

Roll prices / roll quality specifications/ roll dimension tolerances/ roll failures.

(This paper is based on a presentation given at the 16th IAS Rolling Conference on June 9, 2006 at San Nicolas, Argentina: “Commercial and Technical Facts of Rolls and the Roll Industry that are Often Overlooked”).

Dr. Karl H. Schroeder

1. Rolling mill need rolls, for sure, otherwise they can not produce anything. Rolling mills buy rolls from one or more suppliers. The rolls from different suppliers may differ in material composition, surface hardness, performance, tolerances, however they all have to fit into the bearings and should work properly. Roll supplier may add more “values” to the rolls, like guarantees, after sales service, special education for mill-/roll-shop-people or others. Rolls are tools which roll in campaigns before they are re-dresses (on a grinder or a lathe to rebuild the original shape/contour and to eliminate surface damage due to wear and local overloads) till they reach the designed minimum diameter. The end of a campaign is reached, when the volume of an order is rolled or when the finished product gets out of the allowed tolerances.

On average world steel production has been increasing year on year, see picture.

![Graph showing average growth rates](image)

The country with the highest increase - and steel production is China.

Delivery time for rolls has also increased but so far, no mill was stalled due to lack of rolls. This means the roll making capacity is high enough to satisfy even higher demand. This astonishes, as for such a long time the number of roll makers in highly industrialized countries has been decreasing.
Nevertheless, even with high and increasing demand of steel, prices continue to vary. Figure 2 shows the variation just for two years.

<table>
<thead>
<tr>
<th>Month</th>
<th>World Steel Price US $/t</th>
<th>Hot Rolled Steel Coil</th>
<th>Hot Rolled Steel Plate</th>
<th>Cold Rolled Steel Coil</th>
<th>Steel Wire Rod</th>
<th>Medium Steel Sections</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>563.67</td>
<td>661.54</td>
<td>656.17</td>
<td>472.46</td>
<td>596.92</td>
<td>596.92</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>67.40</td>
<td>83.31</td>
<td>67.06</td>
<td>29.89</td>
<td>41.58</td>
<td>41.58</td>
</tr>
</tbody>
</table>

On average, roll consumption today is less than 1 kg of roll for 1 t of rolled steel. For calculation purposes, let us take an average price of a roll of 3 US$/kg then we learn that the roll purchase price normally does not exceed 3US$/t (please compare this figure with the steel price variation!) or roughly 0.5% of steel sales prices. (Rolls are less expensive than the refractory material of the arc furnace in the steel plant.) This means, even the mills would get the rolls free of charge. There would be no impact on the financial result of the mills. Maybe it is fun to bargain rolls prices or to gamble with roll suppliers but without rolls the mill would be in real trouble.
So the goal should be to ultimately forge a “strategic partnership”. This guarantees to have enough rolls in the mill; at the right time, in the right quality and in the right quantity.

2. **Roll specifications** are frequently handed out with roll inquiries.

Rolls should not wear nor break, and should last forever but they wear, break and do not last forever. For a roll supplier, it is important to make “good” rolls. This is particularly difficult for new suppliers. However, roll makers should have a technical service to help the customer/mill to improve roll performance and to avoid costly mistakes in the choice of rolls grades. When a mill is experienced, then the mill personnel usually have a good understanding of what they need and in which area they may have some problems (wear, fire cracks, breakages, or other specific mill related issues).

To find the “best roll grade” and the “best supplier” is a task of TRIAL and ERROR. Easily like this.

Roll quality specifications are often useless, misleading – good for nothing. Often a roll surface hardness is specified, but for what reason? It is well known that some properties of materials are related to hardness but this is proved only for the same type of material. This is not a general law. Often misunderstood is the relation of wear and hardness. Crucial for wear is the type and amount of carbides but not the hardness. For example, when “Adamite of 55 Shore C” is required, the mill will receive (maybe, an alloyed roll based upon Cr, Ni, Mo) a higher price than “normal Adamite”, which performs very similar (this is a waste of money).

Occasionally, even worse, specifications are created (both qualities and mechanical properties) that the supplier should adhere to. However, this is only possible when the requirements/specifications are in accordance with the laws of nature/material science. An example from this year is showing the quality specifications for a new bar mill (Figure 5); for comparison purposes, standard materials are also shown (Figure 6).


<table>
<thead>
<tr>
<th>Material Type</th>
<th>GGG 40</th>
<th>nodular perlitic cast iron</th>
<th>GGG 60</th>
<th>nodular acicular cast iron</th>
<th>GGG 70</th>
<th>GGG 80</th>
<th>AIC 76 ShC</th>
<th>AIC CrNiMo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nodular ferritic cast iron</td>
<td>45 - 50 Sh C</td>
<td>55 Sh C</td>
<td>60 - 65 Sh C</td>
<td>70 Sh C</td>
<td>76 Sh C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Micro structure</td>
<td>ferritic</td>
<td>ferritic</td>
<td>perlitic</td>
<td>martensitic /carbide</td>
<td>martensitic /carbide</td>
<td>martensitic /carbide</td>
<td>martensitic /carbide</td>
<td>martensitic /carbide</td>
</tr>
<tr>
<td>Bending strength N/mm²</td>
<td>1500 - 1600</td>
<td>850</td>
<td>1,250</td>
<td>1,100</td>
<td>700</td>
<td>700</td>
<td>500</td>
<td></td>
</tr>
<tr>
<td>Tensile strength N/mm²</td>
<td>750 – 800</td>
<td>400</td>
<td>500</td>
<td>600</td>
<td>600</td>
<td>550</td>
<td>400</td>
<td>700</td>
</tr>
<tr>
<td>Hardness Shore C, Sh C</td>
<td>45 – 50</td>
<td>55</td>
<td>60 – 65</td>
<td>70</td>
<td>76</td>
<td>76</td>
<td>65 – 70</td>
<td></td>
</tr>
<tr>
<td>relation tensile strength to hardness</td>
<td>2.6 – 2.1</td>
<td>&gt; 2.7</td>
<td>1.30</td>
<td>&gt;2.7</td>
<td>1.40</td>
<td>1.10</td>
<td>0.70</td>
<td>&gt;2.7</td>
</tr>
<tr>
<td>Alternating fatigue bending strength</td>
<td>330 – 350</td>
<td>195</td>
<td>300</td>
<td>248</td>
<td>300</td>
<td>280</td>
<td>200</td>
<td>280</td>
</tr>
</tbody>
</table>

Figure 6: Comparison of standard material properties (GGG 40 to GGG 80) with “mill builder’s fantasy”

1. The hardness has always to be specified within a range.
2. The formula to calculate bending stress does not allow any plastic deformation. The bending test is only allowed for “really brittle materials” like glass. With some plastic deformation, bending tests never give any real figure for the strength. The figures in the specification are unreal.
3. The tensile strength for steel is (up to a limit) proportional to hardness and for standard nodular iron grades as well. The correlation factor for steel is 3.5 then for nodular iron should be >2.7. This is valid for “homogeneous” materials. Factors such as carbides, nonmetallic inclusions, porosities or others, which disturb homogeneity (create heterogeneity of the material) reduce the strength. As a consequence, the correlation factor between strength and hardness is also reduced. Evidently, the correlation factor highlights that “roll nodular iron” behaves quite different from “standard nodular iron” and AIC is no nodular at all. The correlation factor is even less than that for grey cast iron.

4. All fatigue strength values given in these specifications are not accurate or “exact to say” the least (nothing to do with reality). Real fatigue strength figures are much lower. The nominal fatigue stress (M/W) for the fillet (transition neck to barrel) of a roll including the stress concentration factor (usually in the range of 2.2 to 2.8) should not exceed
   a. 150 N/sqmm for carbide-free hardened steel
   b. 120 N/sqmm for Adamite or graphitic steel
   c. 90 N/sqmm for nodular iron
   d. 60 N/sqmm for grey iron.
   In this respect, it is necessary to know the separation forces (the real ones are important not the design rolling loads) and then the M/W can be calculated.

5. The Material 1 specified “NODULAR FERRITIC CAST IRON” and its properties can never exist. Specified hardness is high and the strength will be low due the high amount of carbides. Ferrite is soft and with many carbides there will never be any high tensile and fatigue strength.

6. Materials 5 and 7 show the same properties (I wonder why and how, there should be some effect of “nodular” iron).

It is evident that the specified materials are not available, do not exist, will never exist in the combination of these properties (I personally have to question where this information was sourced from).

Sometimes mill people or their roll buyers ask the roll makers many questions about roll material properties. Sometimes it seems they need some figures for computer modeling, often they just want to prove their pseudo “technical, scientific attitude”.

Never forget: Roll material properties are not related to roll makers - but to roll materials.

Most roll makers never check these properties – for many properties they are not even equipped to measure - which are asked, and they, the roll makers, know, that these figures are not related to roll quality or roll performance!

Often these figures are taken from literature. Actually these figures from all roll makers should be the same!

So, what is the reason to ask again and again, maybe use these figures to (de-) qualify a supplier??

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So, what is the reason to ask again and again, maybe to use these figures to (de-) qualify a supplier??

The following table shows how an answer may look like (this one is from a well renowned roll maker):
And here some more comments on this table full of “non-information”:

- Material properties are independent from the roll maker, they are related to the material but not to the maker.
- Some properties like compressive strength and shear modulus and Poisson’ ratio are determined by the laws of material science (– maybe not in the mind of some people). A figure of 0.5 for the Poisson’ ratio means totally plastic deformation – what is contrary to the “no ductility” for HSS in the example above. A Poisson’ ration of 0.6 would mean “shrinking volume” under tensile stress – what is hard to imagine for any metal.
- Even the dimension of density is wrong (it should be relative density, specific gravity in kg/l (kilo gram per liter).
- That it is forbidden to calculate bending strength for materials with any ductility remains a secret for many engineers, and instead of knowledge they enjoy the wonderful high figures for low strength materials!

Conclusion of chapter 2: Forget about roll specifications and roll material properties. What customers really need are rolls with good performance and which do not create other problems in the mill. A strategically partnership will guarantee that the mill gets what it needs, always.
3. **Roll tolerances.** Some people believe mechanical automatic watches, Figure 7, are very precise intricately manufactured parts, and of course, all parts are decent small. The watches work nicely and somehow accurate- however “precise”? What does this mean besides a nice commercial word?

![Watch Image]

**Product Details**
- **Watch Type:** Wrist Watch
- **Display Type:** Analog
- **Style:** Sports / Outdoor, Prestige
- **Face Structure:** Round
- **Timing Features:** Date / Calendar
- **Movement Type:** Self Winding / Automatic

**Figure 7:** “High precision product” - what is suggested to believe

When we agree that precision means tolerances in relation to dimensions, then rolls have a much higher precision than any mechanical watch. Rolls with the precision engineering of a watch would suggest that they were hand made from a “blacksmith”. Normally it is considered that dimension can be measured down to 0.000 001 m equivalent to 0.001 mm, which is approximately double the wavelength of visible light. In mechanical watches all parts are (of course) extremely small. Tolerances are the same as in rolls (+/-0.005 mm). Dimensions of rolls are hundred-fold that of mechanical watches: so, consequently rolls are hundred-fold more precise than mechanical watches! (Whether this is necessary or not – is a totally other question)
Reviewing a drawing of a roll, (a work roll for a modern mill), it seems 0.01 mm is the tolerance of many dimensions. The parts of the watches will have similar tolerances. However, the parts itself are some-hundred times smaller.

And then, when we look at one detail, the diameter for the steady rest there is the remark “no tolerance”. One diameter on one side should be identical with that of the other side. The drawing allows for “no tolerance” a maximum deviation of 0.025 mm and when we calculate the thermal expansion of the 750 mm diameter we will find 0.009 mm/degree C. People who state such specification have probably never machined a roll and most probably have not even tried to measure the dimensions and check the tolerances. The bearing part of the rolls shows tolerances of +/-0.055 mm, which is very tight. Even the maintenance handbook of the bearing supplier allows a clearance of almost 1 mm. Too narrow clearance, which has been in fashion for a number of years in some mills, has proven to be counter productive causing unnecessary high wear on the work roll necks.

It is well-known that the tolerances of back up rolls, Figure 9, may be crucial for the final product. However, doubts are often raised whether these narrow tolerances are of any use or only increase manufacturing cost. The total indicated run-out, TIR should be zero or close to it. Less than 0.005 mm is normal (even for work rolls). I have even witnessed for a 260 t finished weight back up roll of an aluminum plate mill tolerances of <0.003 mm TIR. Consequently, it took us almost a week to process one roll through final inspection – measurement is extremely critical.

Polished filets of work rolls and even of back up rolls do not increase neck fatigue strength. However, it looks nice, with cosmetic outfit and no technical issue. A good roll design and skilled manufacturing of the rolls is much more crucial.
Perhaps worst of all is the design of keys/keyways in back up roll with hydrostatic/hydrodynamic oil-film bearings (Morgoil). There is no information available of the level of torque acting on the tapered rings, so it is difficult to verify the size/dimensions of the keys. The tapered ring should not move relatively to the roll neck. That is easy to understand but why is there not just one key alone doing this job? What is the reason for two? It is also hard to understand how, even with the tightest tolerances, two can work without plastic deformations of at least one of them and the tolerances are very tight. Whenever a “real torque” is acting on the keys then there is something totally wrong and some parts will break or crack or….

Figure 9: Drawing of a hot strip mill back up roll

Figure 10: Key which fitted nicely into the keyway, was nicely aligned after the roll was in service for about 5 million t of steel

Figure 11: Key with “alignment problems” after the same roll life as the roll in figure 10
In reality, keys even after long time in use look like new, Figure 10 or they look terribly worn out by pushing tapered ring on to the neck and the parts were out of tolerance, not correctly aligned, Figure 11 (both pictures taken in the same mill). I am convinced that one key would be much better than two, lower in cost, easier to handle and can still do the same job.

Conclusion of chapter 3: Tolerances of rolls are tight but often not justified. A strategically partnership between roll user and roll maker will guarantee reliable rolls with consistent precision with meet the requirements of the mill, always.

4. **Roll damages.** Rolls are not supposed to break or show damages of any kind. However, they do. Rolls break (some parts break off, or rolls break into two or more parts), spall, show fire cracks and wear excessively.

It is well-known that the roll materials vary widely in their properties. Carbides improve wear resistance and reduce strength at the same time. Graphite reduces problems with fire cracks. However, high impact results from rolling conditions: rolling speed, reduction, descaling of rolled steel/bars/blooms/slabs, roll cooling and lubrication.

Rolls produced to state of the art manufacturing processes are currently of sound quality and safe to use in almost any application without failures. Thanks to modern mill and roll pass design, every process is computer- simulated and verified.

On the other hand, all mills are strong enough to ruin even the “best roll” either through separating force or torque or thermal stress or whatever.

I firmly believe, after more than 30 years of experience in roll business, over 90 % of all roll damages are caused by rolling accidents and the remaining 10 % are doubtful.

Roll damage normally causes more loss of money due to mill stalls, roll change, loss of production and valuable mill time than the price of one or more new rolls. So, in my opinion, it is much more worthwhile to find the reason of the accident and try to avoid the same problem again than to claim the roll with the supplier. Of course, the roll supplier with his expertise may help to find the reasons or may give hints on how to improve rolling techniques. However, the roll in most cases is a proven tool in “normal quality standards”.

Some remarks on roll failure interpretation and analysis:

1. **“Ductility”** is used very often in technical matters. However, there are different definitions and understandings, so that there are often confusions about the meaning. To call a “material” ductile various test are in use.
   a. As results of tensile tests, the elongation is measured and the reduction of cross sections, both as percentage of the starting dimensions of a standard test bar.
   b. For studying of “brittle fractures”, the result of impact tests versus the temperature is more important.
   c. “Fracture mechanics” was introduced to calculate the strength of component with “existing cracks”, fracture toughness, which is beyond classical mechanics with standard results of mechanical tests (tensile, bending or impact tests)
   d. Roll materials do not require/need ductility. They need occasionally “strength” because in big cross sections there is never a one-dimensional stress situation. Whatever might be written in literature concerning ductility in rolls is wrong.

2. **Plastic deformation** occurs when “shear stress” reaches/exceeds “limit of elasticity” before the component breaks or cracks.

3. **Fracture and cracks** normally occur when “tensile-stress” reaches/exceeds “strength”.

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by Dr. Karl H. Schroeder
4. Cracks and fracture follow maxima stresses. In case it looks odd, then maybe the stress situation was odd too.

5. Cracks, often fire-cracks, sometimes result due to local surface overload during rolling flat products or sometimes fatigue initiated cracks may develop into real fatigue breakages. Crack propagation is controlled by residual stresses. Crack propagation often is progressive. This means the risk of losing more productive roll-life increases the longer a roll with cracks is in service. For some roll grades, it is strongly recommended to redress the surface until no crack remains: AIC work rolls in hot strip mill. Surface-cracks of work or back-up-rolls of strip mills may develop into spalls. Cracks at the bottom of a section mill roll or in the fillet between barrel and neck of high loaded rolls (back-up-rolls) may result in fatal roll breakage.

6. When fracture happens after plastic deformation it is called “ductile fracture” – never seen in roll failures.

7. Fracture without plastic deformation is called “brittle fracture”; this may happen as spontaneous fracture or as fatigue failure.

8. Whether plastic deformation happens before fracture or vice versa is related to the stress situation:
   a. It is possible to deform marble (a really brittle material) plastically (under almost hydrostatic pressure)
   b. Even very ductile materials can break “brittle” without any plastic deformation, for instance under three-dimensional- static-tensile-stress or in the situation of fatigue breakage.
   c. Components of large cross sections (as rolls) typically break without any plastic deformation, “brittle”. – In large cross sections the stress is always three dimensional. Deformations may happen somewhere at the surface, at edges, where only a two-dimensional stress situation exists, like the drive end of a neck or intrusions on the barrel – and this is observed even with very brittle materials like grey iron, AIC or HiCr.

9. To analyze a fracture it is important to study the fracture topography carefully.
   a. Where is the initiation point of the fracture, one or more? Often there is a primary fracture and then consequently other fractures – this may be misleading.
   b. Any fatigue lines?
   c. How did the fracture developed? Fracture lines? Indicate the fracture progress at a photo.
   d. Are casting/manufacturing defects visible and where?
   e. Try to identify the fracture plane; incline, cup and cone, round shaped or sharp ….

10. To find the reason which caused the fracture is even more difficult than to describe the topography because in many cases we do not really know what happened. Basically, we have three different sources of stresses;
   a. Rolling loads, normally just bending, Hertz-calculated pressure, sometimes thrust. However, often fractures are related to rolling accidents where almost everything is possible.
   b. Thermal stress is caused by thermal gradient in the roll.
   c. Residual stresses – very complicated, often not even measured (and then only on the surface – while the fracture may have started sub-surface). Residual stresses are at the highest level in new rolls with straight barrel, normally compression stress at the surface, which are (have to be) compensated by tensile in the inner part of the roll. The more material from the surface is reduced during roll live by machining grooves or by redressing after each campaign, the more the stress level is reduced. When a roll breaks during the first campaign due to thermal stress then the level of residual stresses was possibly too high. In case a roll breaks due to thermal stress in a later campaign then it was caused by abnormal rolling conditions. The level of residual stresses was proved safe under normal rolling conditions encountered during the first campaign(s).
   d. The residual axial tensile stress at the centerline of a roll is never constant from one end of the roll to the other. It follows the dimensions of the roll.
The strength of roll material is never equally distributed. Normally, the lowest strength is close to the centerline of the roll and the roll top end may show lower strength than the bottom cast part.

11. Conclusion about explaining a fracture:
   a. Describe the fracture topography as accurate as possible,
   b. Ask the mill personnel their opinion, when and what happened. Try to find the last bar rolled at the time of the roll failure and take photos (Pictures tell more than thousand words).

There are only very few reasons of roll breakage (surface and wear problems might be different) due to incorrect roll quality:
1. Roll breakage due to thermal stress occurring in the first campaign. In case it happens in a later campaign then it was proved already in the previous runs that the roll is o.k. then the reason has to be found in “rolling conditions”.
2. Sometimes rolls break due to thermal stress and the fracture face shows a (huge) flaw, a casting defect (cup and cone type), then the roll maker has a problem.
3. In case a big steel roll breaks in parts, even without being used, like cut with a knife, then the roll maker has a severe problem.
4. Fatigue breakage of necks (bending or at the flat drive end torque) may be the result of low roll strength. This does not include “corrosion fatigue” of back up rolls what is caused by insufficient roll maintenance (and maybe aggressive cooling water - what should not reach the fillet anyway).
5. Spalls may start at “subsurface impurities”, in the worst case of double poured rolls in the transition zone of working layer and core due to lack of bounding/weak interface.

All kinds of “brittle fracture”, no matter of collar or barrel end breakage or whatever are caused by rolling accidents. The famous “back up roll barrel end spalling” is not caused by low roll strength. It is a mill problem (There is a number of technical papers available detailing this).

Conclusion of chapter 4: Rolls costs have little impact on the financial results of a company; however, roll failures may cause loss of valuable rolling time and production. It is important to find the reason of roll failures – with or without the help and experience of a roll maker – and to avoid repeating the same or similar failures. Just to claim a roll does not disclose any problem of the mill and just makes the show of doing nothing,( we call this a “pseudo activity).

A strategically partnership between customers and BRC will guarantee the mill:
- To receive the right roll at the right time in the right quality
- To avoid all useless discussions about roll specifications and material properties
- To receive rolls which fit the mill
- To get technical support, when ever it might be opportune
- BRC adds more valuable information to the rolls

The goal is satisfaction by a WIN – WIN situation.