NEW DEVELOPMENTS FOR BACKUP ROLL MATERIALS*

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Abstract

GP is a manufacturer of cast compound BUR with ductile steel core. These rolls combine a ductile, low-alloyed steel core with an outer layer material that is resistant to abrasive wear, corrosion and fatigue. The impact on backup rolls in hot and cold rolling applications is more demanding since new powerful mills have been developed.The product mix of the mills is dominated by a high share of AHSS. GP has developed a new high alloyed BUR with a ductile core. The shell is alloyed with Cr, Mo and V with a Chromium level of almost 8%. In some applications cast backup rolls have a disadvantage compared to forged rolls, since the cast structure provide natural insufficiencies. In mills with tough rolling conditions the integrity of the roll is depending on the fatigue limit of the roll material and here a forged structure provides advantages due to lacking casting defects. GP made trials to improve the properties of the 5% Cr grade by applying an additional deformation of the shell. The objective of these trials is to produce a compound backup roll that combines the advantages of a ductile steel core with the good properties of a forged outer layer.

Keywords: Backup Rolls; Compound Rolls; Wear Resistance; Contact Fatigue

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1 INTRODUCTION

The business for rolls has experienced some fundamental changes in the last years. These changes include significant restructuring and consolidation of the global roll industry as well as roll manufacturing processes and roll material development. The impressive growth of the Chinese steel industry in the last 15 years was followed by the installation of substantial capacities for roll manufacturing in China. The established roll producers from Europe, America and Japan benefitted for quite some time from the great demand of rolls from the Chinese rolling mills. Today the situation has turned around and China is supplying the global markets not only with steel products, but is more and more offering rolls to rolling mills all over the world. As a result of this development and together with a moderate global steel demand, we have already seen a downsizing of roll production capacities in particular in Europe. Since the year 2000 Europe has shut down plants for cast and forged rolls in Spain, Belgium, France, Germany, and Sweden with a total capacity of more than 60.000 tons. Consolidation took place with the purchase of the Åkers Group by Union Electric in 2016 forming the biggest roll supplier in the western world [1].

The development of new steel grades has also rapidly progressed in the last decade. The major driving force here is the environmental pressure of the automobile industry to produce vehicles with lower weight by implementing steels with higher strength. Tensile strength could be improved from “low strength steels” with 270 MPa to AHSS steels with more than 1.700 MPa. However, this gain is paid with a loss in ductility by decreasing the fracture elongation from 50 to 10 percent (Figure 1). Only TRIP or TRIPLEX steels provide a combination of high strength and high ductility. The deformation and stress induced transformation of the austenite into martensite provides excellent in service properties that improves the safety in crash situations [2].

The evolution of modern steel grades has also influenced the development of roll grades. The deformation resistance of the product in a rolling operation is proportional to the material strength. Hence the high strength of modern steel grades require rolling mills with increased deformation power. The maximum rolling force of a conventional outmoded plate mill was at a level of 10MN per meter barrel length. Today the latest generation of plate mills reaches 20MN and the mill designers are still planning to also double the driving torque.

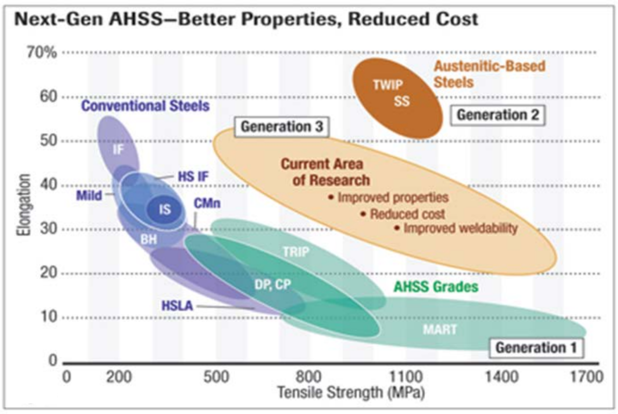

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Figure 1: Steel grade development and corresponding mechanical properties

Roll producers need to offer sophisticated roll materials to compete in these challenging market conditions. In recent years the main focus on roll material research has been the development of HSS grades for work rolls. The new generation of wear resistant materials with high hardness levels does also increase wear and mechanical impact on the backup roll. The new backup roll generation of Gontermann-Peipers is developed to provide solutions to these market conditions.

2 ROLL MANUFACTURING

Gontermann-Peipers (GP) was founded in 1825 and is one of the most experienced and well established producers of work and backup rolls. GP is the only manufacturer of compound backup rolls produced by the static double pouring (DPS) process (Figure 2).

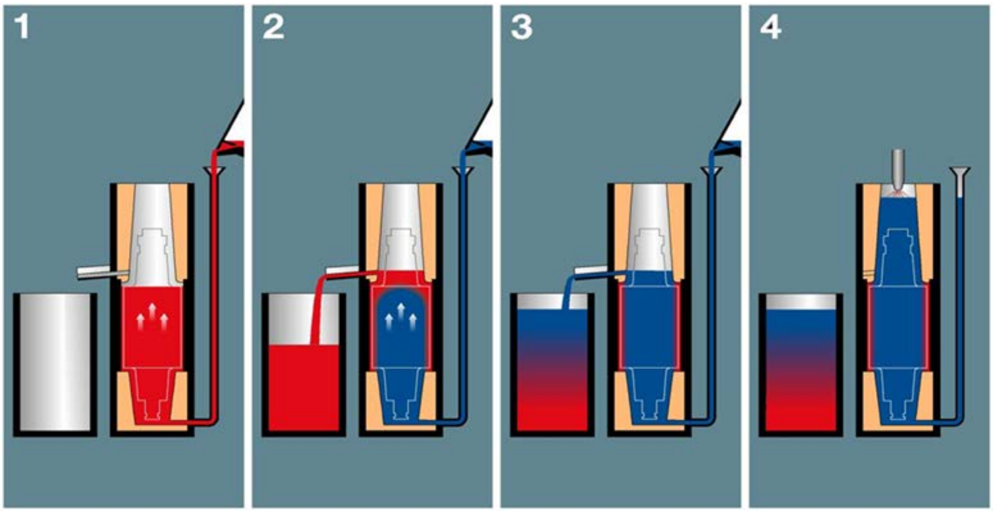


Figure 2: The static double pouring process of GP

A vertical mold consisting of the iron chill for the roll barrel and the sand forms for the upper and lower neck is prepared in the casting pit and connected to a bottom pouring runner system. The mold includes an overflow device just above the chill for the barrel. At first the mold is filled with the high alloyed shell material for the working layer of the roll just until the overflow device (1). Due to the high cooling rate the liquid steel will start to solidify at the iron chill and form the outer working layer of the roll. When the required thickness of the layer is achieved the ductile steel for the core and neck of the roll is poured (2). The part of the alloyed steel that has not yet solidified will be pressed out of the mold via the overflow system (3). In the final step the overflow is closed and the upper neck is filled. In order to achieve a directional solidification and avoid center shrinkage the mould is equipped with a hot topping device (4). Depending on the roll dimensions the solidification takes between 5 days and 3 weeks. After that the mold is removed and the roll is prepared for heat treatment and machining.

Today all other backup rolls with steel core in the market are monobloc rolls that are either cast or forged. Three facts describe the actual situation in the backup roll industry:

- All suppliers produce the same qualities with varying Cr-content from 1-5%
- Main difference between suppliers is the production method, cast monoblocs, forged monoblocs or double poured compound rolls.

- Today the market is demanding more forged rolls. Forged rolls are expected to have a better damage tolerance and contact fatigue resistance in particular in highly loaded applications. Also the price for forged rolls has come down to more reasonable levels.

Forged monoblocs can show superior properties due to the additional plastic deformation process. The forging eliminates casting defects like micro-porosities and provides a compact microstructure with favorable fine grain size [3]. On the other hand all monobloc rolls have to compromise between the properties of the barrel and the core/neck area. High alloying is beneficial for the requested properties on the barrel like wear, compressive strength and corrosion resistance but derogatory for ductile core and necks. For this reason monobloc rolls, either cast or forged, have a limited potential for further improvement. Up to now, all monobloc backup rolls are produced with Cr-contents not higher than 5%. This seems to be the natural limit. Compound backup rolls have natural advantages compared to monobloc rolls. A ductile core and neck material is required to absorb the frequent impact stresses during the rolling process and reduce damage on the roll. During heat treatment even rolls with large geometries can be entirely and homogeneously austenitized and quenched. A temperature excess on the roll surfaces is not necessary. A homogeneous temperature before hardening leads to lower residual stress levels that are formed during the phase transformation and plastic deformation. The risk of barrel breakage is drastically reduced. Compound backup rolls almost never fail with barrel breakage in the rolling mill. Another advantage of compound rolls is a homogeneous hardness level down to the scrap diameter. The properties remain stable during the entire life of the roll.

With most recent developments GP takes the advantage of the DPS process to manufacture static compound backup rolls. Compound rolls have a significant potential for further improvement. GP has already successfully established a spuncast 8% Cr backup roll with a nodular iron core for cold rolling applications with low roll forces [4]. A similar alloying concept is now combined with a ductile steel core and already successfully tested in various hot and cold rolling applications. More than that GP is also working on combining the advantages of compound rolls and the forging process. The first prototypes of a forged 5% Cr compound backup roll have been tested in a German cold rolling mill. The first trial for a hot mill is on the way.

3 REQUIREMENTS ON ROLLS

A typical hot rolling stand consists of work rolls and backup rolls (4-high). Backup rolls transfer the rolling force and work rolls transfer the torque. In modern mills work roll shifting and bending is applied to realize optimal profile and flatness requirements. Hot rolling and cold rolling are different due to temperature and thus the deformation resistance of the rolled product. High temperature facilitates the deformation but provides an additional burden in the rolling process. Rolls in service are underlying multiple loads as illustrated in figure 3 [5].

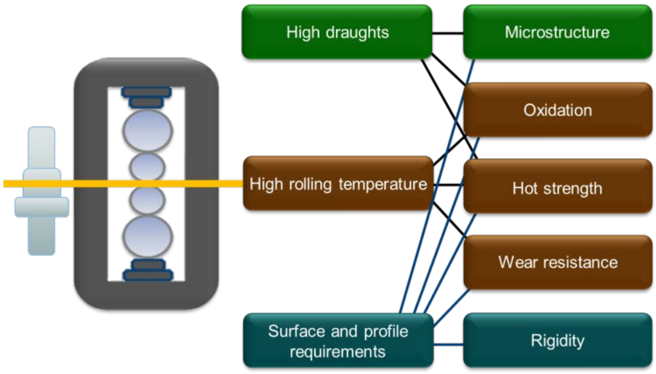


Figure 3: Influence factors and their interactions in a hot rolling stand

The requirements on backup rolls are different from work rolls. The main demand is a high reliability during operation. Further favorable properties are a suitable hardness level with very constant and homogeneous hardness to guarantee long campaigns and a good surface. High wear resistance and good corrosion resistance enable low diameter reduction after each campaign. A low hardness drop leads to constant backup roll properties down to end diameter.

3.1 In-Service Loads of Backup Rolls

The load of backup rolls during service is quite complex and different from mill to mill. Many parameters like mill type, rolling position (top or bottom), rolling parameters (rolling force, rolling speed, cooling and lubrication), mill actuators (roll shifting and bending) and roll dimensions influence the actual loading situation of the roll [3,6]. There are in principle three different reasons for a failure of a backup roll in normal operation:

- Abrasive wear
- Hertzian pressure and contact fatigue
- Bending impact in the transition zone of barrel and neck (fillet)

3.2 Abrasive wear

A popular model to describe macroscopic wear was developed by Archard [7,8,9]. The wear A is depending on the rolling force F, a wear constant K, the roll hardness H and the speed difference between work and backup roll Δv.

$$A_{Archard} = \frac{KF}{H}|\Delta v| \qquad \textbf{Equation (1)}$$

According to equation (1) wear only occurs with a speed difference between work and backup roll. Speed differences in the contact area between work and backup roll are caused by imperfect roundness of the rolls, thermal expansion and wear. Beside this the wear increases with the rolling force and friction coefficient and decreases with high hardness. In a tractive contact zone that exists between work and backup roll there are areas of slippage ($\Delta v \neq 0$) and areas of sticking ($\Delta v = 0$). Wear will predominantly occur in areas of slippage, whereas areas of sticking will suffer from contact fatigue.

3.3 Hertzian pressure and contact fatigue

The main load of a backup roll in a 4-high rolling stand is the contact pressure with the work roll. According to the Hertzian theory two cylinders are under a specific pressure q when their surfaces are in contact. The maximum compressive stress

Pmax is depending on the specific pressure q, the radii R1, R2 and the Young Modula E1 and E2, or the Poisson ratio respectively. The point of maximum stress P_{max} is always below the contact plane (Figure 4).

$$P_{max} = \frac{2 \cdot q}{\pi \cdot b} = \sqrt{\frac{q}{\pi} \cdot \left(\frac{1}{R_1} + \frac{1}{R_2}\right) / \left(\frac{1-\upsilon_1^2}{E_1} + \frac{1-\upsilon_2^2}{E_2}\right)}$$ **Equation (2)**

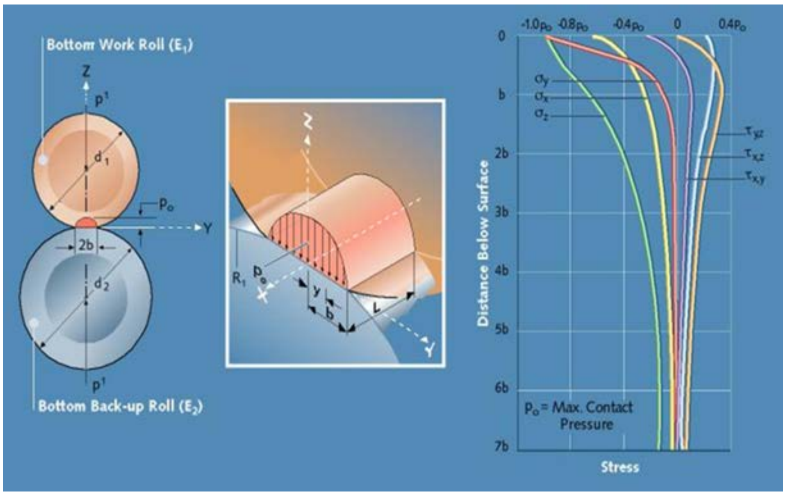


Figure 4: Hertzian stress distribution

The related maximum shear stress τ_{max} is then calculated as follows:

$$\tau_{max} = 0{,}304 * P_{max}$$ **Equation (3)**

The material strength is typically measured in the tensile test. In order to describe the loading during the rolling process it is favorable to use the ideal compression test. Similar to the rolling condition, the compression test is using an uniaxial loading. The maximum Hertzian stress Pmax for the tested material is derived by entering the 0,2% compressive yield strength $\sigma d_{0,2}$ into formula 3 [10]:

$$P_{max} = \tau_{max} / 0{,}304 = \sigma d_{0,2}/0{,}608 = 1{,}645 * \sigma d_{0,2}$$ **Equation (4)**

In fact the material behavior is practically not ideal. Even if the 0,2% compressive yield strength of the backup roll material is calculated not be exceeded, it could be that material inclusions or very small material defects can lead to partial plastic deformation by local stress concentration. The 0,2% compressive yield strength is than locally exceeded.

Roll contact fatigue is a result of the Hertzian stresses applied to the roll. This load is changing dynamically during the service due to changes in the surface profile of work and backup roll. The contact fatigue is developing due to repeated plastic deformation in the contact zone (work hardening). Wear and contact fatigue are strongly linked together. A part of the work hardening is removed by the “natural” wear in the rolling process; the remaining part is removed by the “artificial” wear during the grinding process. When the work hardening is not removed, it can grow until the compressive strength of the material is reached and the roll will crack. In the worst case this can lead to a massive spalling of the roll.

Wear has an additional impact on contact fatigue. The natural wear profile will reduce the length of the contact zone and thus raise the forces. With higher forces the work hardening will increase as well and the risk of spalling will grow. A good wear resistance is therefore an excellent prerequisite for operational safety.

3.4 Bending impact in the fillet area

Beside wear and contact load on the barrel backup rolls are in particular loaded by rotating bending fatigue in the transition/fillet area between barrel and neck (Figure 5).

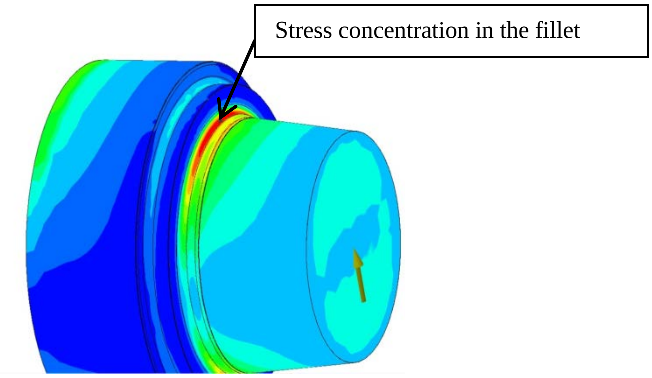


Figure 5: FEM-simulation of bending stress distribution in a back-up roll

Due to the dimensional step of diameters between barrel and neck a stress concentration is occurring in the fillet area. Mill designers calculate required bending fatigue strength of 240-300 MPa in this area. With given layout of a backup roll the bending fatigue strength can be increased by material selection and adjustment of a favorable residual stresses during heat treatment. Compound rolls will allow using low alloyed steels with a high degree of ductility. This is hardly possible for high alloyed monobloc rolls. Specific cooling parameters can initiate favorable compressive stresses in the fillet area, which will help to reduce the risk of neck breakage.

4 NEW DEVELOPMENTS

The trend in rolling mills towards higher loads has revealed the natural deficits of cast and forged backup rolls and increased the pressure on roll producers. GP was forced to intensify the efforts in developing competitive products. The natural road to success was to concentrate on the given benefits of our production process, a unique way to manufacture compound backup rolls. The double pour static (DPS) process of GP is worldwide the only process to manufacture compound backup rolls with steel core. It allows high alloying of the working layer in combination with a mild ductile core. Monoblocs rolls have a natural limit for improvement, since they always have to compromise between the contrary demands of barrel and neck properties. This fact offers potentials for GP to differentiate from other roll suppliers.

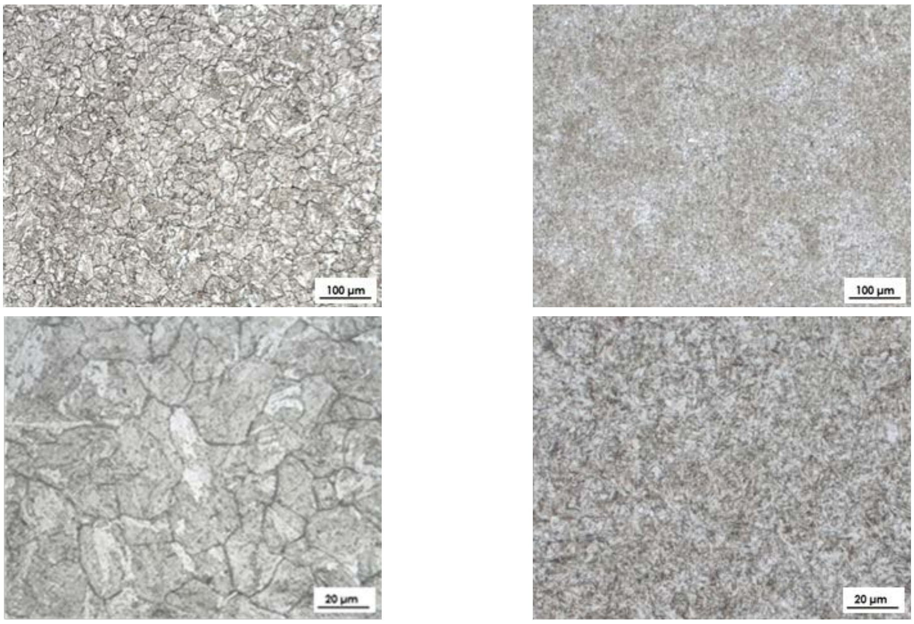
4.1 Backup Roll Material Development

Base material for the first backup rolls was the ball bearing steel 100Cr6 with 1% Carbon and 1.5 % Chrome. With increasing rolling forces the average Cr-content raised to 3-5 % and the C-content lowered to 0.4%. Further pass sequence optimization as well as the efforts of the mill designers to further increase the rolling forces require maximum allowed Hertzian stresses of 2.500 MPa. This corresponds to a minimum 0.2 % compression limit of 1520 MPa. Conventional low alloyed backup roll materials have a pearlitic structure that is good for reversing rolling stands. The hardness level is around 340-390 HV. The state of the art 5% Cr backup roll has a bainitic microstructure and is used in the majority of the hot and cold strip mills. The hardness level is around 520-630 HV.

In order to meet the demands of continuously growing rolling forces and contact pressure GP has started development work to modify the existing backup roll grades by increasing the Cr-content. With growing Cr-content the structure is changing to martensite at a hardness level up to 680 HV. Actual investigations on laboratory level indicate that the modified material shows the best combination of material strength, wear resistance and toughness together with a good machinability.

4.2 High alloyed compound backup roll AST90X

The objective of this project was to develop a new backup roll material with a higher operational safety compared to the conventional 5% Cr cast backup roll. The mean to reach this objective is a high strength material with an improved castability to provide a fine microstructure with reduced casting defects and excellent wear resistance. The advanced properties are achieved with a fine microstructure of tempered martensite and homogeneously distributed fine carbides. Wear resistance is the key to evenly distributed rolling forces and moderate work hardening. It provides a stable roll profile and allows longer campaigns with a better roll performance.



AST70X AST90X

Figure 6: Microstructure comparison

Figure 6 shows the microstructures of the conventional 5 % Cr Backup Roll AST70X and the high alloyed grade AST90X. The 5% Cr grade is characterized by a bainitic structure with rather coarse grain sizes. The structure of the AST90X is much finer due to finely dispersed carbides that act as nuclei during grain formation. Due to the higher alloy content a martensitic microstructure is achieved, which comes along with a higher hardness level. In combination with the fine carbides the wear resistance is improved.

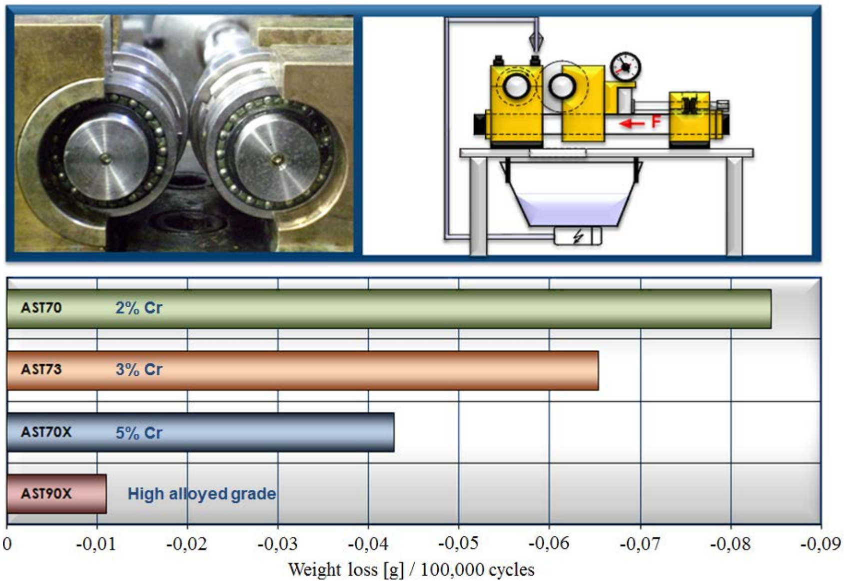


Figure 7: Laboratory wear test

Figure 7 illustrates the results of the laboratory wear test. Backup roll materials with varying Cr-content have been tested. Wear resistance is improving with growing Cr-content. The weight loss of the new grade AST90X is about 4 times lower than the conventional grade with 5% Cr.

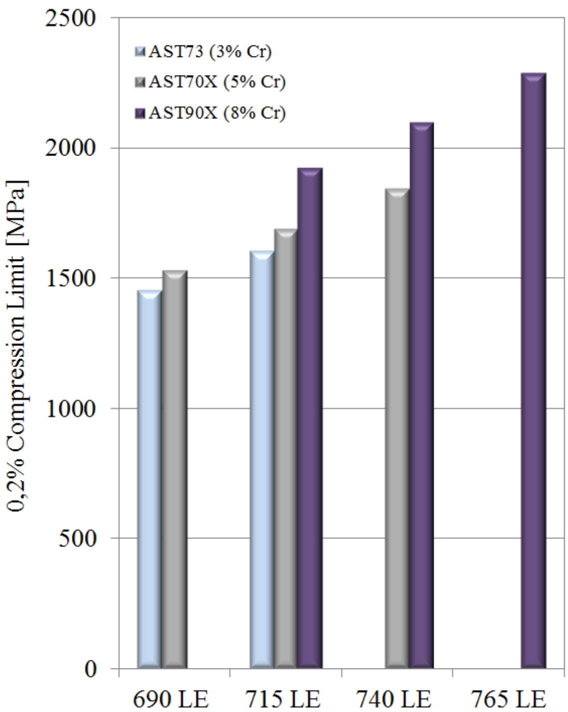
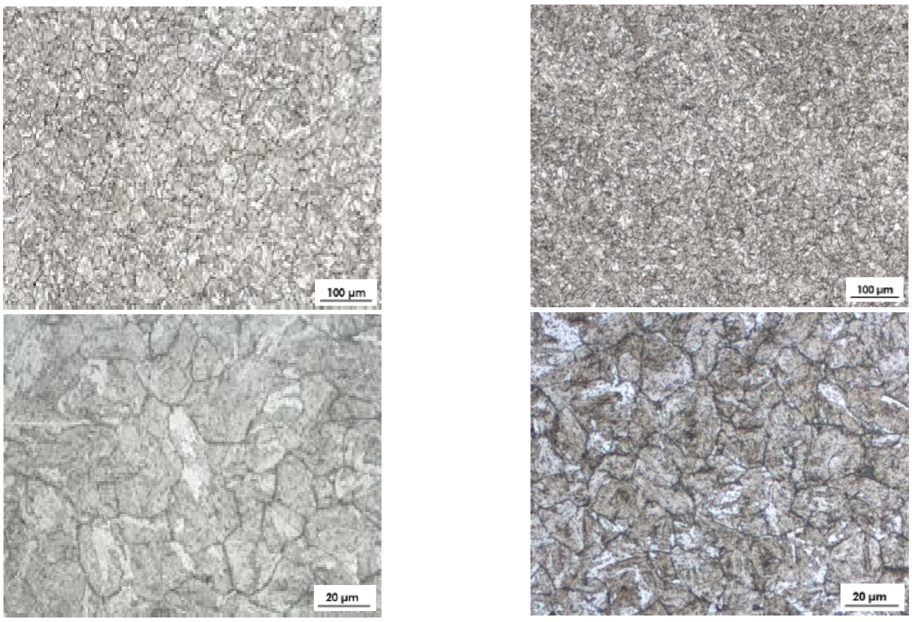


Figure 8: Compressive strength of backup roll materials at different hardness levels

The 0,2%-compression limit of the AST90X grade at different hardness levels in comparison to other backup roll grades is illustrated in figure 8. Due to the martensitic structure of this grade we can achieve hardness levels between 715- 765 Leeb E which is slightly higher than the hardness range of conventional 5% Cr backup rolls. At same hardness levels the 0,2% compression limit of the AST90X is about 15% higher compared to AST70X. This provides a better resistance against local overloading as well as higher contact fatigue strength.

4.3 Forged compound backup roll AST70XF

About 30 years ago rolling mills used with a few exceptions entirely cast backup rolls. Due to before mentioned reasons the share of forged backup rolls was growing progressively. The double poured backup grade AST70X with 5% Cr-content showed a tendency to contact fatigue failures in particular when used in very demanding mills. The objective of this development is to improve the damage tolerance of the AST70X by improving the material properties with an additional plastic deformation during production. At the same time the advantages of a compound roll towards a monobloc roll shall not be challenged. The rolls are cast in the static DP process with required oversize in diameter. This is followed by a deformation in a 4000 t forging press. The temperature is controlled in such way, that deformation is concentrated on the outer layer. The as cast structure is broken up and refined down to the transition zone of shell and core material. Figure 9 shows the microstructures of the conventional 5 % Cr Backup Roll AST70X and the new grade AST70XF after heat treatment. The cast roll shows a much coarser grain size, whereas the grain size of the forged roll is much finer due to recrystallization during deformation. Besides this both rolls show the typical bainitic microstructure.



AST70X Cast AST70XF Forged

Figure 9: Microstructure comparison

To be able to measure a better damage tolerance the results of the mechanical testing are particularly important. Figure 10 shows results of tensile tests that have been performed on the conventional cast grade and the new grade with additional deformation. The ultimate tensile strength (UTS) was improved by 15% with the additional deformation process. The increase is moderate since we have tempered bainite as a dominant phase in both structures.

* Technical contribution to the 55º Seminário de Laminação e Conformação de Metais, part of the ABM Week, October 2nd-4th, 2018, São Paulo, SP, Brazil.

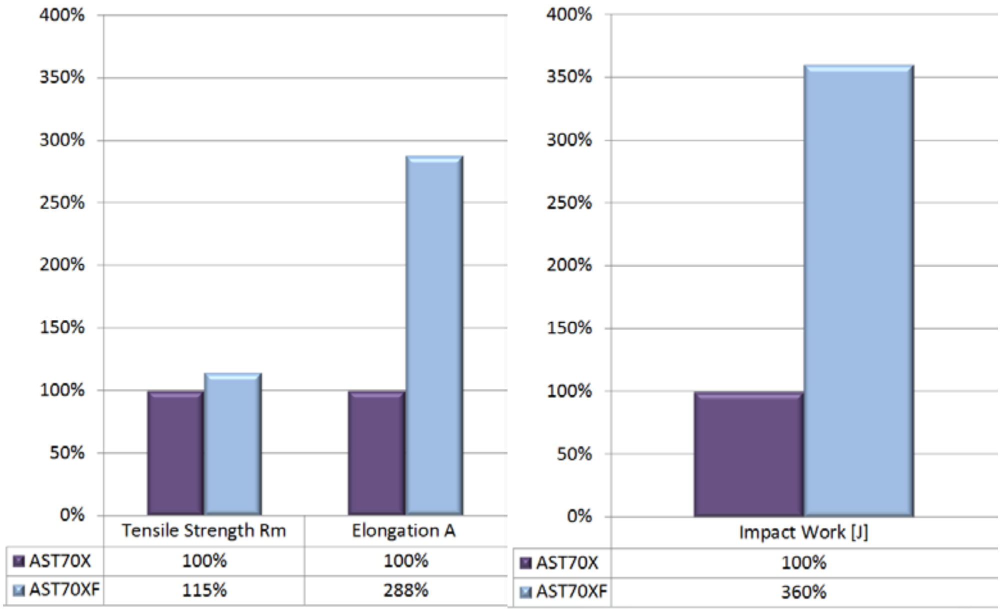


Figure 10: Mechanical properties of cast and forged 5% Cr backup rolls

The elongation at fracture improved almost 3 times in the forged sample. This indicates a much better ductility of the material. An increased toughness can be observed at the impact test. The impact work for un-notched samples increased 3.6 times. The absence of casting defects and a finer grain size have a positive impact on the overall toughness of the material. The new grade provides a better damage tolerance and the potential to withstand critical rolling conditions.

5 DISCUSSION

GP has already produced and shipped a number of rolls of both new grades. In order to proof the superior operational safety the trials are performed in mills with critical rolling conditions and the tendency to have problems with conventional roll materials. The results of the mechanical testing in combination with achieved microstructures indicate a good potential for better service properties. However, it is difficult and time consuming to collect results from the industrial testing. Backup rolls fail predominantly in the last 30% of their service life. The microstructure is getting coarser and physical properties are getting worse at the inside of the usable working layer. The toughness of the roll is decreasing. Depending on the mill a backup roll lifetime can last several years. In order to get viable results from backup rolls test one has to wait until the roll is used down to the critical diameter. GP is naturally interested to get results as quick as possible. For this reason we have made agreements with some customers to make additional diameter reductions during the trials. This will bring the rolls faster to the critical diameter and provide performance results in a reduced time frame.

At this stage the field results are limited but positive. Both grades are used in various hot and cold rolling applications, some of them already for 2 years. It is difficult to measure operational safety but none of the rolls failed and we see a tendency to less subsurface cracking and reduced amount of grinding between campaigns. The highly alloyed grade AST90X shows 10-40 % less wear in two hot mill applications and 10% improved t/mm performance in a cold mill application. The forged compound roll

AST70XF shows a high reliability and no tendency for subsurface cracking in highly loaded mills.

6 CONCLUSION AND OUTLOOK

The developments in the market for backup rolls are challenging the load-bearing capacity of the actual materials. A growing demand for high strength steels and continuously increasing rolling forces are putting pressure on backup roll suppliers. For many years the alloying limit for backup rolls was 5% Cr since the majority of backup rolls are monobloc rolls either cast or forged. The limit for higher alloy content is the required ductile properties of the neck. Only compound rolls have the capacity to go beyond this limit. Gontermann-Peipers developed the cast high alloyed compound backup roll AST90X to meet the market demands. Laboratory results and field trials are promising. A second project of GP to cope with growing market demands is the forged 5% Cr compound back roll AST70XF. This roll shows improved material properties due to the additional deformation step and does not challenge the advantages of a compound roll towards a monobloc roll. Both new developments are unique in the market and bear a high potential to differentiate from other products. For the future GP is investigating the feasibility of combining the two developments. The idea is to develop a compound backup roll that combines the excellent wear resistance of the high alloyed material with the improved ductility and toughness achieved by the additional deformation.

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