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NEW MATERIALS FOR WORK ROLLS IN HOT MILLS WITH FOCUS ON PLATE MILLS[1]

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Abstract

New HSS shell materials have proven to increase significantly tonnage, service life and performance of work rolls in hot mills compared to conventional shell materials like high chromium iron HCR, high chromium steel HCS or indefinite chill double poured ICDP. Introduction of new HSS materials allows to cut down significantly on production costs and to increase the availability of the mill. The results are quite general and can as well be applied for related production units in Steckel mills, hot strip mills or continuous strip plants.

Keywords: HSS work rolls; Hot mills; Multiple performance increase.

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Introduction

With an experience of more than 155 years, Karl Buch has specialised on the production of top quality rolls for the steel industry with weights up to 80 t.
Due to the capacity for the production of high unit weights, Karl Buch is one of the leading companies for new developments in the area of roughing mills and plate mill applications.
Particularly in the **sector of roughing rolls and for plate mill rolls**, Karl Buch is one of the market leaders. Karl Buch has an export quota of 75 % and delivers in more than 40 countries worldwide.
In plate mills, plate is rolled usually from slabs of 200 – 300 mm thickness down to a finished thickness of ca 4 mm.
Depending on the type of mill, whether the material is rolled in a single-stand or a two-stand application, the number of passes can vary considerably. In plate mills usually the plate is not reheated after the slab has left the furnace.
The number of passes can be as high as 13 in Steckel mills (two stands) and 29 in some (two-high) plate mills.
Which roll material is applied is a question of process parameters such as load, reduction, plate temperature, contact time, bite angle, etc. in order to reach a minimum of wear.

Which Core to use - Lamellar Cast Iron vs Nodular Cast Iron

In single stand mills, separating forces of 2000 t - 7000 t are common. The specific pressure in the roll gap usually is in the range of 150 Nmm^{-2}.
These conditions allow the usage of a (lamellar cast) grey iron core in many four-high applications. Grey iron has a tensile strength of ca. 220 Nmm^{-2}, but Karl Buch can also provide material of increased strength. Most mills, however, use a (nodular cast) ductile iron core because of higher requirements for the Young modulus and tensile strength. This applies in particular to two-high stands where separating forces, bending forces and torque have to be considered. The tensile strength of ductile iron amounts to ca. 400 Nmm^{-2}, our top materials can reach higher values. Also in some cases, bending fatique strength is a limit (Table 1).

Table 1. Comparison parameters core materials

Material	Tensile Strength [Nmm^{-2}]	Bending Fatigue Strength [Nmm^{-2}]
Lamellar Cast Iron	220 - 300	100 - 140
Nodular Cast Iron	400 - 600	200 - 220

Choice of Shell Material – Stress and Wear

Mechanical parameters of shell materials are given in Table 2.The shell material is exposed to external stress caused by the separating force onto the rolls which leads to an elastic deformation of the rolls and in particular to intense pressure between work roll and backup roll. A maximum of the resulting Hertz’ian residual (shear)

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Table 2. Comparison parameters shell materials

Shell Material	Tensile Strength [Nmm^{-2}]	Bending Fatigue Strength [Nmm^{-2}]
ICDP	250 - 600	80 - 120
HCR	600 - 700	250 - 270
HCS	800 - 900	290 - 310
HSS	850 - 1000	300 - 400

stress σ_0 builds up below the surface of the work roll and depends upon roll size and Young modulus of the shell material:

$$\sigma_0 = 0{,}52 * P_{max} \quad \text{with} \quad P_{max} = \sqrt{\frac{P\left(\frac{1}{r_1}+\frac{1}{r_2}\right)}{\pi(1-\nu^2)\left(\frac{1}{E_1}+\frac{1}{E_2}\right)l}}$$

r = roll radius
E = Young modulus
l = barrel length
ν = Poisson's number

For a four-high stand with a separating force of ca. 4000 t, Hertz'ian residual stress can be as high as 200 – 300 Nmm^{-2} and should not exceed the bending fatigue strength of the shell material. Otherwise, plastic deformation occurs which finally leads to cracks.
Further decisive parameters regarding wear of work rolls in plate mills are

- the temperature exposure to the steel (ca.1200 °C) and the heating up of the roll surface,
- the high contact times (ca. 50 ms) in connection with large bite angles of the roll,
- separating force,
- campaign length,
- appropriate cooling,
- scale formation.

All these factors contribute to the formation of fire cracks, which are the limiting factor in the lifetime of a work roll in a plate mill.

HSS - Currently the best Material!

Formation of Fire Cracks

In the roll gap, the outer surface of a work roll, e.g. in a four-high stand of a plate mill, can heat up as high as 600°C. Subsequent cooling of the roll surface induces shrinkage of surface material (Fig. 1, 2).

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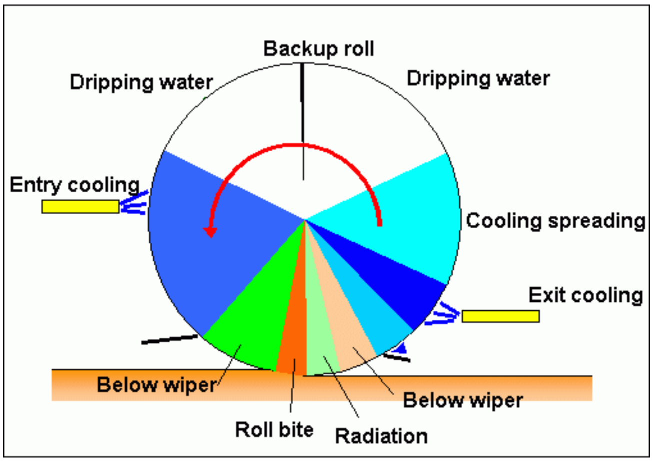

Figure 1. Scheme of roll gap.

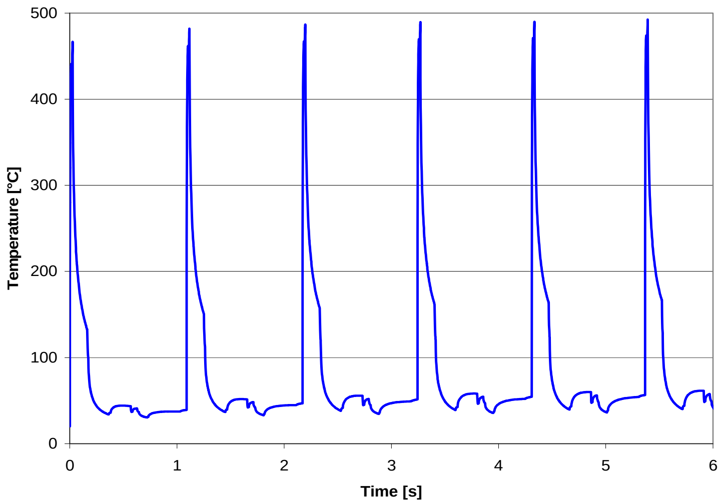

Figure 2. Surface temperature during rolling.

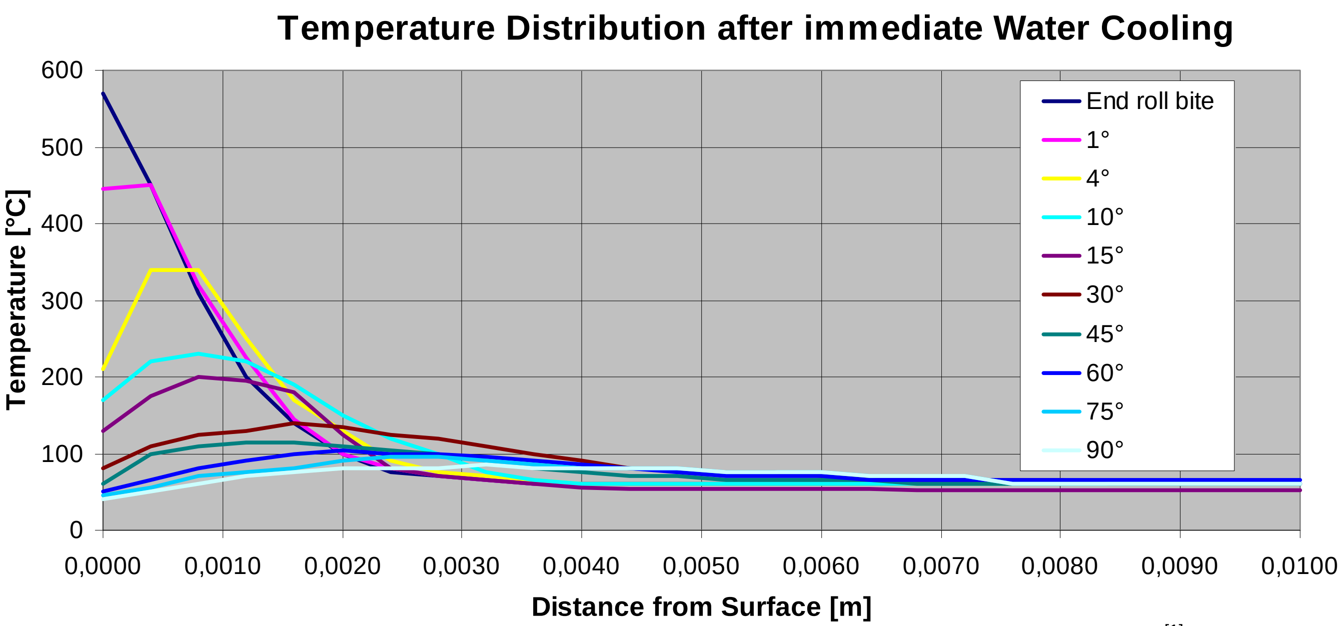

Figure 3. Temperature distribution underneath the surface after immediate water cooling. [1]

Since there is still heat accumulation below the surface in the first moments of cooling, the following mechanisms can occur, depending on the contact time (Fig.3):

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a) The top surface material shrinks to such an amount (high contact time), that its tensile strength is exceeded and cracks are initiated on the surface. Repeated cooling/heating cycles advance crack growth
b) Shrinking of the surface in the elastic regime (low contact time) causes plastic deformation of the hot material underneath by compression. Repeated cooling/heating cycles finally lead to breakage of the material from underneath the surface by exceeding its compressive strength.

For a), cracks are formed if

$\sigma_{m1} > \alpha_k \cdot R_m$, σ_{m1} = tangential surface stress, α_k = notch factor, R_m = yield strength

In each cycle of rolling, the surface material is exposed to a hysteresis of temperatures and tensions, starting freshly at A and running through B, C, D to E (Figure 4).
The following steps can be observed:

- Cooling of compressed material induces a horizontal tension σ_{m1}
- If horizontal tension during subsequent heating exceeds yield strength, cracks are initiated
- Cracks grow perpendicular to the surface and form a cellular network (Fig. 5)

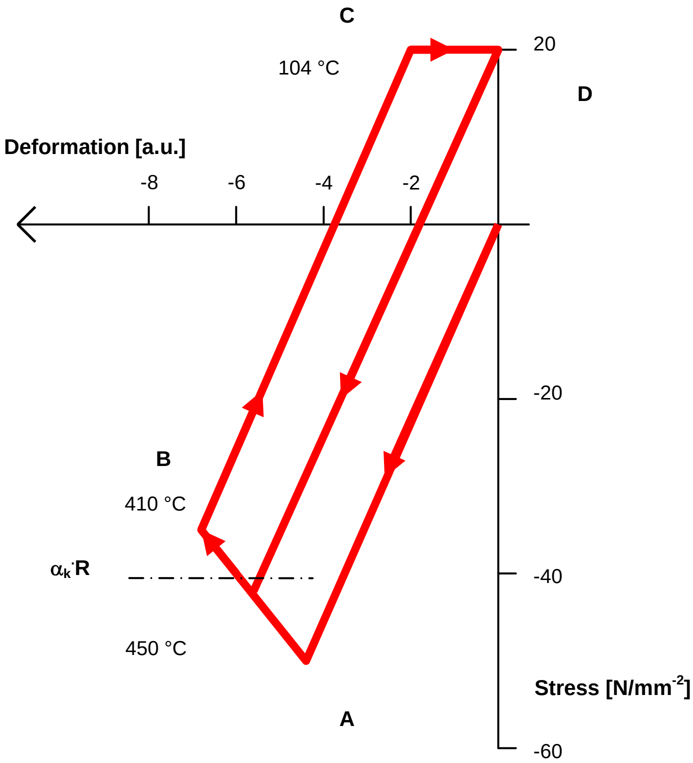

Figure 4. Hysteresis of stress at roll surface,

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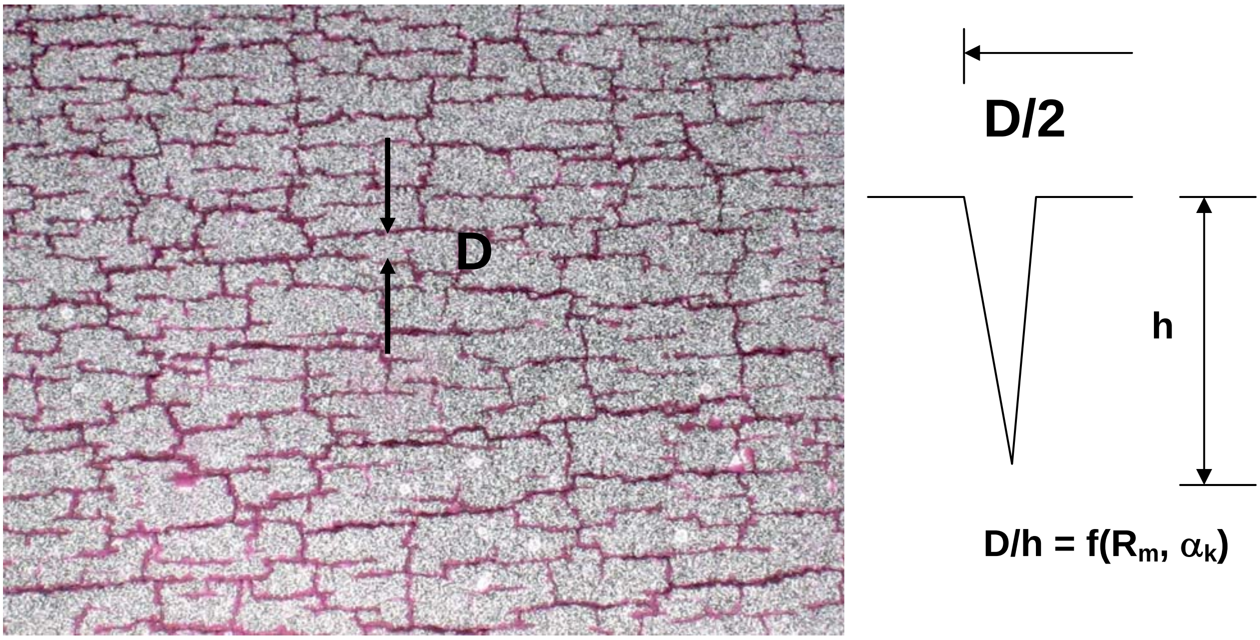

Figure 5. Formation of network of fire cracks

The ratio D/h (cell diameter D, crack depth h) is a function of yield strength R_m and notch factor α_k as well as contact time, temperature and material properties [2].

$$\mathbf{D/h}= \sqrt{\frac{8\cdot(1+\mu)}{(1-\mu)}} \bullet \sqrt{\frac{R_m\cdot(1+1/\alpha_k)}{\sigma_{th}-2/3\cdot R_m}}$$

σ_{th} = theoretical tensile stress on the surface

Since cracks are formed , if $\sigma_{m1} > \alpha_k \cdot R_m$, a critical peak surface temperature exists. Is this critical temperature exceeded, crack formation occurs.

$$T_{krit1}=\frac{(R_m/\alpha_k)-B+E^*\cdot\alpha\cdot T_{01}}{A+E^*\cdot\alpha}$$

α = thermal expansion coefficient, T_{01} = average Surface temperature, A, B = fitting factors

In a first approximation, the temperature stability of a roll (shell) material is proportional to its yield strength. Therefore, stability towards fire cracks increases in the following series:

ICDP < HCR < HCS < HSS

The critical temperature T_{krit1} for crack formation increases in this series going from ICDP over high chromium iron HCR and high chromium steel HCS to HSS.
The following table summarises some key data for ICDP, HCR and HSS materials exposed to a sheet of 1020°C (Table 3).

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	HSS	**HCR**	**ICDP**
Surface Temperature T_S	542 °C	551 °C	563 °C
Critical Temperature T_c	545 °C	483 °C	382 °C
Cell Diameter D	free of crack	0,56 mm	0,12 mm
Crack Depth h	0,04 mm	0,19 mm	0,313 mm

Table 3. Comparison of critical Temperatures for HSS, HCR and ICDP d_{barrel}=800 mm, roll velocity v = 1,5 m/s, reduction 11 mm, contact time 0,04 s, T_{core}= 60°C, T_{sheet} = 1020°C. [2]

New HSS Materials for the Market [3]
Karl Buch provides different types of HSS materials depending on the needs of the customer and the application. Considering application and mill conditions, KB is able to customize HSS materials individually if required (Table 4).

Table 4. HSS Qualities of Karl Buch

Type HSS	Synonym	Carbide Content	Application
HSS Type A	Semi-HSS	4 – 6 %	Early stands of continuous roughing mills, tandem roughing stands
HSS Type B	HSS	7 – 10 %	Reversing roughing stands, late stands in continuous roughing mills, work rolls early stand finishing mills, plate mills
HSS Type C	HSS	10 – 14 %	Finishing stands hot strip mills, cold mills, F1 – F4
HSS Type D	Super-HSS	10 – 12 %	Finishing stands F3-F5

In Karl Buch HSS materials, the content of carbon and carbide is increasing from HSS Type A to D. Thus, HSS Type A and B rolls are best suited for applications where fire cracks are a predominant problem. HSS Type C and D rolls are more applied in finishing stands, where high surface hardness and superior wear properties are required.
All HSS materials generally consist of a martensitic matrix with special carbides of high hardness. A sophisticated mix of alloys and heat treatment ensures a fine granulation and a small grain size (Fig. 6).

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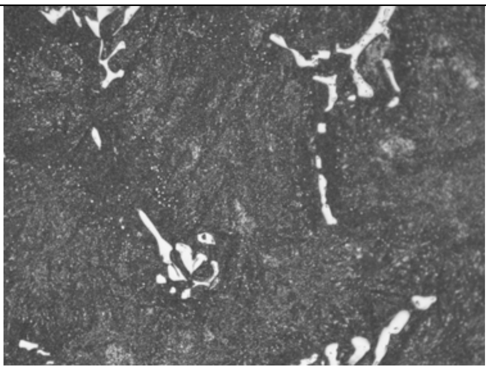
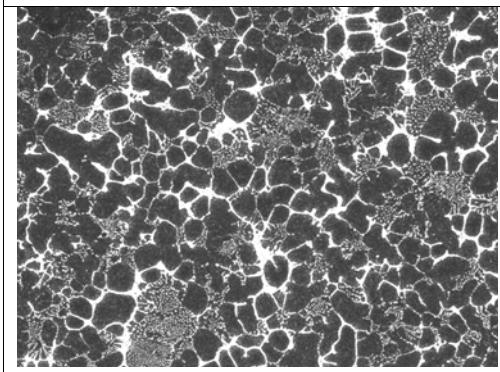
 1:500	**HSS Type A** Tensile Strength: ca. 850 MPa Young Modulus: ca. 225000 MPa Hardness: 75-80 ShC HSS material with high alloy and low carbide content.
 1:50	**HSS Type C** Tensile Strength: ca. 890 MPa Young Modulus: ca. 225000 MPa Hardness: 78-84 ShC HSS material with high alloy and high carbide content.

Figure 6. Microstructure of selected HSS Shell Materials.

The surface hardness is reached by a bundle of measures:

- Hardness of matrix (martensitic > bainitic > pearlitic)
- Alloying with super-hard carbides
- Generation of residual compressive stress in the roll shell

In particular the last point, to adjust residual stress in the roll shell, is of great interest to us. Residual stress is implemented through the casting process and heat treatment and needs to be measured and calculated. Fig. 7 shows calculations for the circumferential distribution of residual stress for a large work roll. [4] The data are in agreement with measurements.

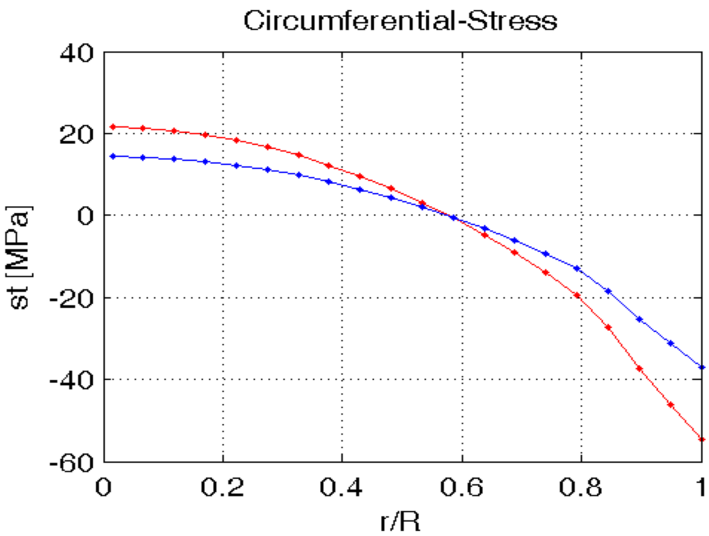


Figure 7. Circumferential component of residual stress in a HSS roll as function of related radius.

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Residual stress is not so critical in four-high applications, but needs to be considered in two-high stands. Since the sum of all stress components in a roll is zero, compressive stress in the roll shell is compensated by tensile stress in its core. Rolls in a two-high stand are exposed to considerable bending forces which should not exceed the strength of the core, which is already under residual stress. Furthermore, temperature gradients within the roll can add a considerable contribution of tensile stress and induce breakage.

Performance - HSS Rolls are a most cost-effective solution

As indicated above, HSS rolls are showing less wear profile than HCS, HCR and ICDP. Therefore, tolerances of the steel product can be maintained on much larger campaign lengths. In particular, if rolling speed and cooling conditions allow the absence of fire cracks, a much smoother steel surface is achieved even after extremely long campaigns. Of course the evaluation of rolled length and/or tonnage per mm consumption of shell material is not the only factor to be considered. Less roll changes increase the availability of a mill and the extra rolled tonnage will justify in any case higher costs for the HSS material.

Furthermore, it has to be discussed together with the customer how stable mill conditions are. In case mill accidents occur often such as lack of cooling e.g. by blocked cooling nozzles or lack of motor power, damages have also to be considered with HSS rolls. If stock removal due to these accidents exceeds certain limits, the loss of expansive roll material might not justify its price. Therefore, the introduction of sophisticated roll materials is a complex task and involves for sure not only the roll shop but also mill operations and production planning. Long campaigns are needed to generate the full cost advantage of HSS rolls. Therefore we abdicate from showing marketing performance figures but rather advise to work out performance guidelines together with the customer. We have established very successfully HSS rolls in industry and have achieved a multiple increase in performance compared to conventionally applied shell materials.

Outlook

Cost effective large HSS rolls of diameter > 1000 mm but also smaller sizes are provided by Karl Buch via a new double poured spin cast process. Optimisation of the casting process guarantees rolls with a perfect interface shell/core. Optimisation of composition and casting parameters allows to reduce the sensitivity of the rolls to fire cracks significantly.

Combined efforts of roll manufacturer and customer are needed to enjoy the full benefits of HSS rolls. Furthermore, extreme attention to and high precision of the grinding process are a must to achieve maximum performance.

Karl Buch will be glad to work out joint projects together with the customer.

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Figure 8. Typical plate mill work rolll.

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