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CO_2 MITIGATION AND ENHANCED STEEL SCRAP RECYCLING WITH NEW DIRECT STRIP CASTING PROCESS (DSC)

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ABSTRACT

Direct Strip Casting (DSC or also termed single belt casting) is not only a new and economic way to produce sheet metal in standard and new steel grades. It also allows mitigation of carbon dioxide production and increase of the fraction of steel scrap used in the steelmaking process.

Carbon dioxide mitigation is achieved by energy savings in the production process. As the steel is cast on a single belt in thicknesses below 20mm and the steel strip is directly fed to the hot rolling mill, energy for reheating and rolling of the steel strip is saved.

Due to improved acceptance towards tramp elements in the DSC process an increased fraction of scrap metal can be used. Respectively the amount of steel that is produced from ore via the carbon-dioxide intensive blast furnace is reduced. Additional CO_2 mitigation is achieved.

DSC is a promising way to produce new alloys as e.g. high Manganese content High Strength and Ductility-steels (HSD). High strength and ductility in HSD-steels are a result of the TRIP- (transformation induced plasticity) and TWIP-effect (twinning induced plasticity). The production of these alloys is difficult or even impossible in the conventional continuous casting plants or thin slab casting plants. The use of these steel alloys in the transportation sector will allow important carbon dioxide reductions as a result of lightweight construction.

1. INTRODUCTION

The focus of the work described in this paper is on the eco-efficient effects correlated with the Direct Strip Casting Process (DSC). Due to its particular suitability for the production of high-alloyed steels for lightweight construction, a glance is also set on the eco-efficient effects combined with the application of new steel grades.

Regarding the steel making process concerning CO_2 mitigation and energy consumption it may be useful to subdivide the process in the subsequent steps: 1st iron making, 2nd steelmaking and refining and 3rd casting. Taking into consideration a product life cycle from "cradle to grave" also the CO_2 emissions and energy consumption for the extraction, processing and supply of the process-educts for ironmaking (coke, ore, etc.) have to be taken into account on the one hand side and on the other hand side CO_2 emissions and energy consumption for the production, use, recycling and disposal of the considered product are to be recorded.

2. THE DSC-PROCESS: STATE OF THE ART

In the Direct Strip Casting Process (DSC or also termed single-belt casting) the liquid metal is cast on a belt made of copper or steel moving at the casting feed rate (*fig. 1*). The solidifying metal is cooled at high heat fluxes. These high heat fluxes are in generally realised by liquid jet cooling of the belt from its bottom side. Typical thickness of the cast sheet is 6 to 15 mm.

The casting may be shielded completely to keep the metal under controlled gas atmosphere upon solidification. This gas atmosphere may be adjusted in zones to different inert or reacting (e.g. reducing) atmospheres. After passing a cooling and thermal equalisation zone the metal sheet is directly hot reduced to thicknesses below 5 mm and coiled.

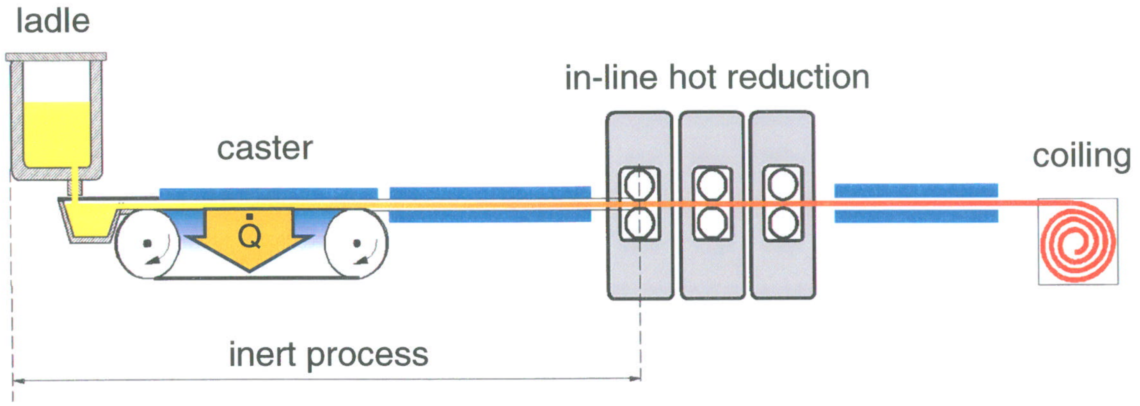


fig. 1: Direct strip casting process: schematic view

Unlike in conventional casting techniques segregation and formation of cavities is avoided by realising high cooling rates and thin casting thickness. From experiences with existing experimental and pilot plants high production capacities of industrial scale DSC-lines can be expected.

Besides advantages concerning energy consumption a variety of technological advantages could have been proven in experimental studies. An advantage resulting especially from the high cooling rates is that steels with high percentage of alloying elements may be cast with very low appearance of segregations and without using casting flux powder. Both of these facts are favourable for the production of steel grades with high manganese content [1]. Due to the extraordinary mechanical properties of these HSD-steels (High Strength and Ductility) they have high potential to find widespread application for lightweight construction. In the transport sector important energy savings and carbon dioxide mitigation can be reached by using such materials. These steels contain approx. 12-25% wt. of manganese and usually smaller quantities of aluminium, silicium and carbon. They are to be classed in the group of the Advanced Austenitic High Strength Steels (AAHSS). Their extraordinary mechanical properties are resulting from the TRIP and TWIP effect where phase transition (TRansition Induced Plasticity) and twinning (TWinning Induced Plasticty) upon deformation result in very high deformation rates and high tensile strength (*fig. 2 and 3, tab. 1,* e.g. [2]). *Fig. 4* shows the example of a probe of a HSD-steel with TWIP-effect that is twisted about 10π, which equals a deformation in the outer line of about 100%. This deformation value surmounts the deformations reached in the tensile tear tests at the moment. Since the transformation effects can be reset by heat treatment, the properties of the cold rolled material can be adjusted in very large ranges.

fig. 4:HSD steel probe with TWIP-effect twisted about 10π. The resulting deformation is up to 100%

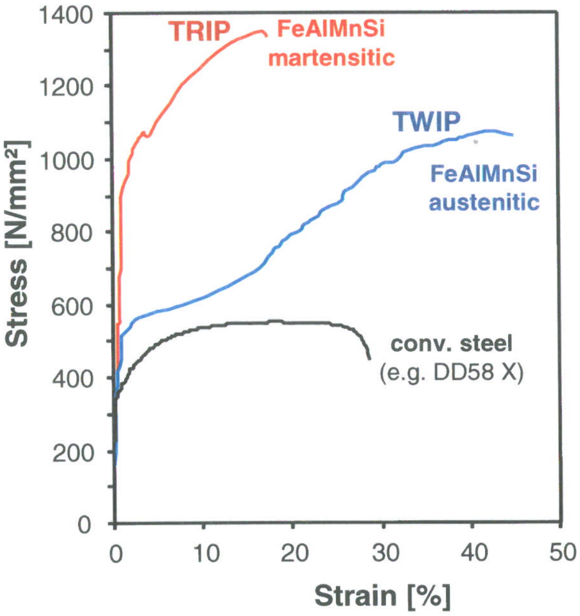


fig. 2: Properties of HSD-steels with TRIP- and TWIP-effect compared to conventional steel in a tensile tear test

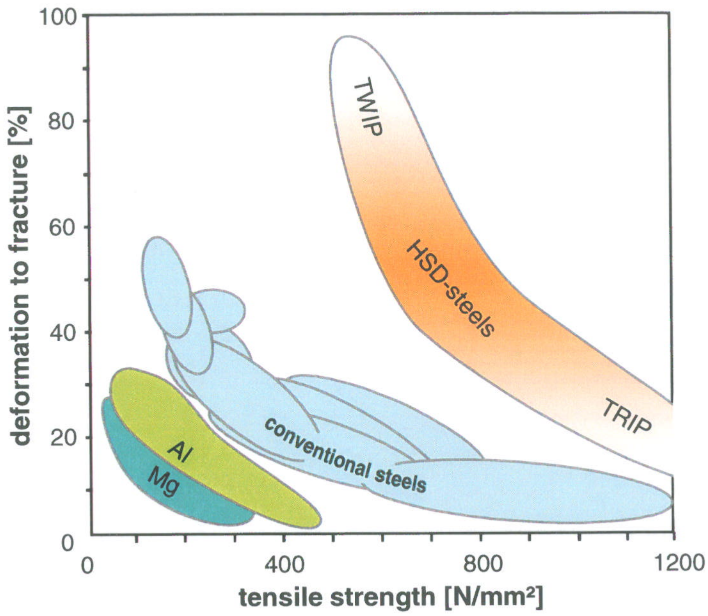


fig. 3.: classification of HSD-steels according to tensile strength and deformation fracture

tab. 1.: Examples for properties of HSD-steels with different alloys and heat treatments, own experiments and [1)] after Gräßel [2]

No.	Yield Strength [N/mm²]	Tensile Strength [N/mm²]	Fracture Elongation
1.	230	600	60%
2.	970	1.300	22%
3.[1)]	220	620	93%
4.[1)]	440	950	45%

3. SUSTAINABLE EFFECTS OF AND LINKED TO THE DSC-PROCESS

The eco effects like energy savings and CO_2 mitigation that can be reached using the DSC-process are mainly linked to the following process properties:

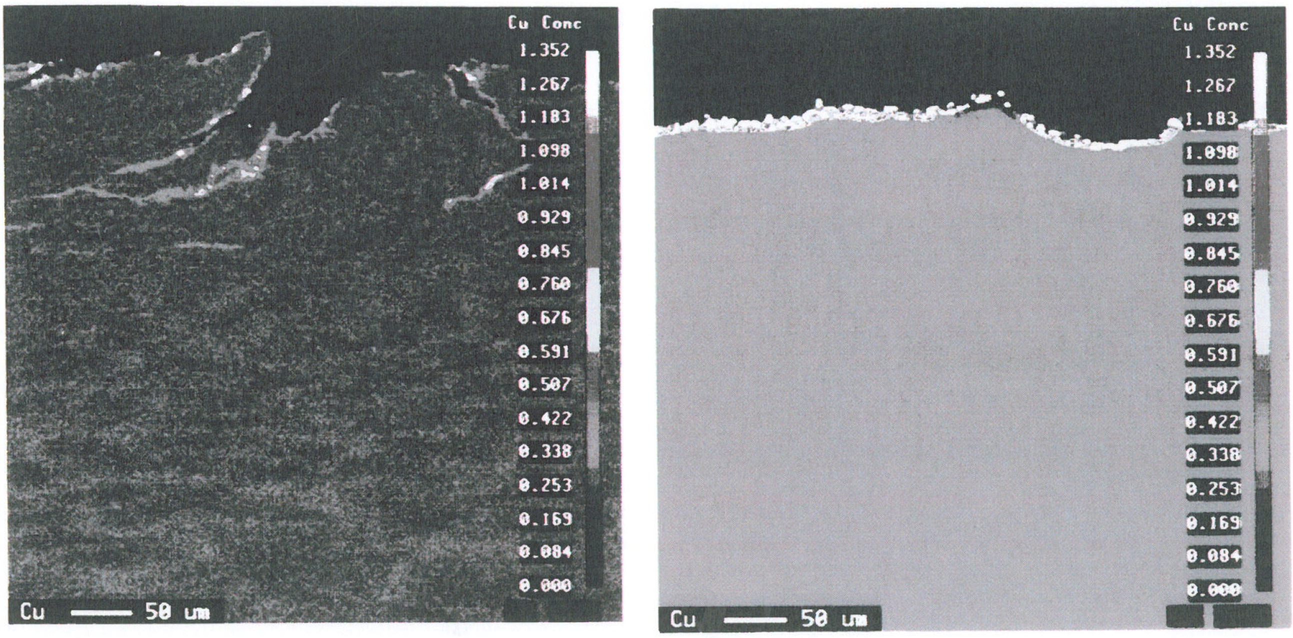
1. reduced degrees of hot-reduction and no reheating of the cast material;
2. the possibility to use a raised amount of recycled steel for the production of most steel grades due to improved tolerance towards tramp elements;
3. the application of new steelgrades produced with the DSC-process is giving the opportunity to realise energy savings through lightweight construction e.g. in the automotive sector.

3.1 SUSTAINABLE EFFECTS DURING STEEL PRODUCTION

A mass and energy balance for the processes casting and hot rolling: Direct Strip Casting (DSC), Conventional Slab Casting (CSC), and Compact Strip Production (CSP, also referred to as Thin Slab Casting) gives as result the amount of primary energy spent to produce one ton (1Mg) of steel. While in conventional slab casting 3.5 GJ/Mg_{Steel} are needed in Thin Slab Casting 2.1 GJ/Mg_{Steel} are used and in Direct Strip Casting only 0.8 GJ/Mg_{Steel} are used. The details for this calculation are described in [3]. Comparing steel produced with a DSC-process with one compared in conventional slab casting 2.7 MJ/Mg_{Steel} primary energy are saved. The economies result especially from the fact that practically no reheating is effected and that hot rolling is reduced.

3.2 SUSTAINABLE EFFECTS RESULTING FROM THE USE OF STEEL SCRAP

The production of steel from scrap needs importantly less energy than the production from ore. While for the production of oxygen steel (blast furnace route) 20.4 GJ/Mg_{Steel} are consumed, for the production of electro steel from steel scrap recycling (electric arc furnace) only 7.9 GJ/Mg_{Steel} are needed. A limitation to the use of electro steel is given by the appearance of tramp elements (Cu, Sn) in steel scrap. Cu and Sn are causing quality problems especially in the production of flat products. The average amount of tramp elements in steel scrap is expected to raise about approximately 20% within the next 20 years [4]. Copper is concentrating near the surface upon casting as liquid phase between the ferro-oxide and steel. At high temperatures it is diffusing along the grain-boundaries where it may produce a low-melting-point alloy with iron. In these areas the steel is weakened and may crack under stress. In *fig. 5.a* the Cu-concentration close to the surface of thin slab cast steel is shown. One can easily observe the high Cu-concentrations close to the surface. In *fig. 5.b* the Cu-concentration close to the surface of direct strip cast material is shown. Although the overall Cu-concentration is importantly higher the copper is spread homogeneous in the volume. By increasing the amount of steel scrap used in the steel production the amount of primary energy consumed can be decreased importantly. Assuming that the amount of steel scrap used in steel production is raised by 20% wt. , 2.5 GJ/Mg_{Steel} primary energy can be saved.



a) Cu = 0.24 % wt.: Thin Slab Cast (CSP): Oxide formation and diffusion along grain boundaries: tendency for crack formation

b) Cu = 0.4 % wt.: Direct Strip Cast (DSC): uniform Cu-contribution

fig. 5.: Microprobe measurements on cross sections close to the surface, the colour is indicating the local copper concentration

3.3 SUSTAINABLE EFFECTS RESULTING FROM THE USE OF NEW STEEL GRADES

As mentioned above, DSC is a favoured production process for new high alloyed steel grades. Therefore the production and use of High Strength and Ductility Steels (HSD-Steels) shall be regarded within this paper.

An example is given to demonstrate the capacities of CO_2 mitigation that can be reached using HSD-steels: Considered is a mid-class car with a body in white using HSD-steels. A reduction of the mass of the body in white from 300 kg to 240 kg can be realised using the advanced mechanical properties of the new steel grades. The resulting amount of primary energy saved is 3.5 GJ/Mg_{Steel}.

Adding the economies made for the production of cars with a body in white made of HSD steel grades: a) using the DSC process, b) raising the amount of steel scrap used and c) weight reduction for the body in white, an overall of 8.7 GJ/Mg_{Steel} is saved. The carbon dioxide mitigated amounts to 0.67 Mg/Mg_{Steel} which is a reduction about 32%.

Regarding the lifecycle of the considered car the fuel saving due to the reduced weight of the car-body and resulting energy reduction from secondary weight savings is about 2.5%. Secondary weight reduction can be realised since a lot of car components can be scaled down as a consequence of the reduced car weight without affecting the cars driving performance: this is the case for e.g. the motor, chassis and brakes. This secondary weight reduction is assumed to be 1/3 of the weight reduction of the body in white. Calculated on a car lifetime of 130,000 km a CO_2 mitigation of 1,690 kg/Mg_{Steel} per car is reached and an economy in primary energy of 19.1 GJ/Mg_{Steel}. This surmounts the economies made during the production of the body in white.

4. FUTURE PROSPECTS

To enable industrial implementation of the benefits from the DSC-Process and HSD-steels some further research and development has to be effected; e.g. to find the optimal route for the making of high manganese steel (ore used, primary and secondary metallurgy, etc.) and to know more about the properties of different alloys to be able to choose the right material composition for a successful market implementation.

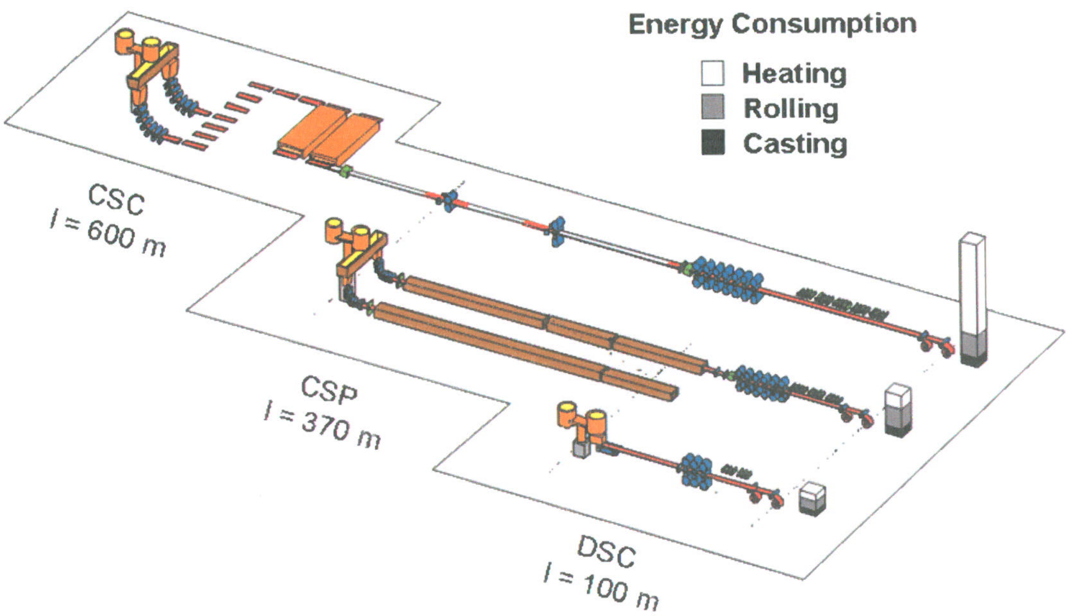


fig. 6: Process setup and energy consumption for the processes CSC (Conventional Slab Casting), CSP (Compac Strip Production) and DSC (Direct Strip Cast)

From an economic point of view, the use of the new technologies is attractive compared to conventional and state of the art techniques and products. Comparing the DSC process with the conventional techniques CSC and CSP, not only the energy consumption is reduced but also the amount of space and equipment needed, leading to economies in the investment (*fig. 6*). Furthermore the alloying costs for HSD-steels are relatively low compared to state of the art high alloyed steels (*fig. 7*).

Due to the combination of technological and economical advantages linked to the DSC process and HSD-steels a widespread industrial implementation is very likely to be realised in the near future.

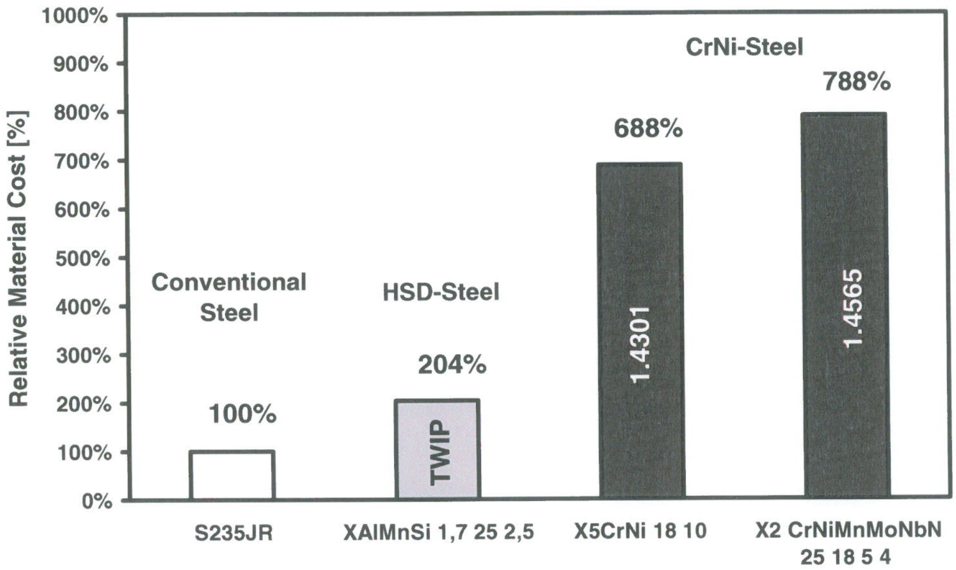


fig. 7: Relative material cost for iron and alloying elements

5. CONCLUSION

By using the DSC-process an important amount of energy can be saved in the production of rolled steel products. The energy savings are realised due to decreased material reduction by rolling, the abandonment of steel reheating and the possibility to use increased amounts of steel scrap with high contents of tramp elements. These economies in energy are also linked with a potential for financial economies, which is an important strength of the DSC process with regard to its industrial implementation.

But even more important for the eco-efficiency as well as the industrial implementation of the DSC-process is its role for the production of new steel grades such as high Mn-content steels. In the given example the energy savings and CO_2 mitigation that can be realised in the car lifecycle surmount the eco-effects upon steel production (*tab. 2*).

To be able to use the benefits of these new technologies further research and development work has to be accomplished.

tab. 2: Summary of realisable energy economies and CO_2 mitigation due to the use of DSC-process and new high alloyed steel grades

	Energy Savings [GJ/Mg_{Steel}]	**CO_2 Mitigation** [Mg/Mg_{Steel}]	**Explanation / Remarks**
production of hot-rolled steel	*2.7*	*0.67* (combined for the three rows)	*primary energy consumption compared to production by CSC*
increased amount of Tramp-element laden steelscrap	*2.5*		*amount of used scrap increased about 20% wt.*
use of HSD-Steel for car production	*3.5*		*saving 20% material*
use of HSD-Steel in a car-lifecycle	*19.1*	*1.69*	*reduced fuel consumption due to weight-reduction.*
SUM	***27.8***	***2.36***	

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REFERENCES

[1] Gigacher, G.; Bernhard, C.; Kriegner, W.: *Eigenschaften hochmanganhaltiger Stähle unter stranggießähnlichen Bedingungen*; BHM, 149. (2004), 3, pp. 112-117

[2] Gräßel, O.: *Leichtbaustähle auf der Basis Fe-Mn-Al-Si*, Diss., Technische Universität Clausthal, 2000

[3] Kroos, J.; Redeker, C.F.; Eichholz, H.; Spitzer, K.-H. et al.: *Energiesparende Herstellung von Leichtbaustählen nach dem DSC Verfahren*; Schlussbericht BMWA 0327289A, 06.2004

[4] Noro, K.; Takeuchi, M.; Mizukami, Y.: *Necessity of Scrap Reclamation Technologies and Present Conditions of Technical Development* , ISIJ Int., 37(1997), No.3, pp. 198-206

[5] Grässel, O.; Frommeyer, G.: *High-strength and ultra-ductile FeMn(Al,Si) TRIP/TWIP light-weight steels for structural components in automotive engineering*, Stahl und Eisen 122 (4), 65-69 (2002)