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DEVELOPMENT OF Nb CONTAINING STEEL AT SAIL FOR AUTOMOTIVE APPLICATION: PRESENT STATUS AND FUTURE PROSPECT

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Abstract

The automotive industry has encouraged steel producers to develop high strength formable steels in both hot rolled and cold rolled gauges. The paper discusses the measures by SAIL to meet the expectation of the customers. Hot rolled high strength steels micro-alloyed with niobium have been developed for auto chassis application whereas high strength cold rolled grades have been developed for moderate forming application. The developmental work for dual phase, TRIP and ultra fine-grained steel has also been highlighted.

INTRODUCTION

The Indian automobile industry has witnessed an impressive growth of 25% during 2005 and the trend is likely to continue with the surge in the national economy. In the coming years, the automotive sector in India is about to witness a dramatic change by way of type of steel, design and fabrication methods. Steel Authority of India Ltd., the leading steel producer in India, has been responding to these changing conditions by developing new grades to suit the market requirement.

The paper discusses the efforts by SAIL towards development of varieties of high strength formable grades (both hot rolled and cold rolled) micro-alloyed with niobium. Keeping in view the future requirement of the auto sector, SAIL has taken various initiatives to develop new grades of steel on the laboratory scale, which has also been highlighted in the paper.

Hot Rolled Formable Grades

The automobile industry is one of the largest consumer sectors for hot rolled steel products, mainly used for fabricating wheel rims, wheel discs, chassis and other structural components. These components require moderate to severe forming operations, which can be met by formable hot rolled steel grades. The compositional requirement of these grades depends on the strength level and severity of forming. In general, low carbon aluminum killed steels with restricted sulphur and phosphorus, microalloyed with niobium, is processed to meet their forming and strength requirement.

Auto Chassis Grades

High strength hot rolled plates and sheet are used by the automakers to manufacture long chassis members, frame side members, cross members for heavy, medium and high commercial vehicles (HCV, MCV and LCV). The important grades of steel presently used for auto chassis applications are E-34, E-38, BSK-46 and SAPH-45.

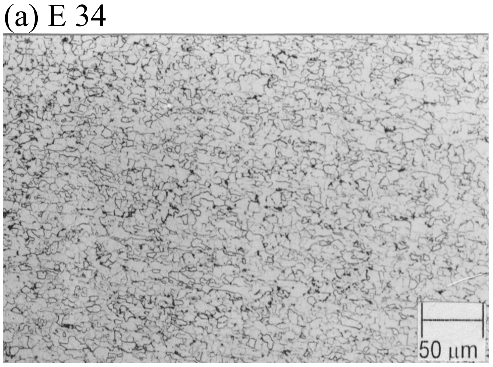
Steel grades equivalent to E-34 and E-38 are killed quality steel micro-alloyed with Nb. SAIL has developed these grades through LD-LF / VAD-CC route of the Bokaro Steel Limited (BSL) and the Rourkela Steel Plant (RSP). A thermomechanical simulator (Gleeble-3500C) available at RDCIS, SAIL has been extensively used to optimize the alloy composition. Multi-pass simulation including reheating, deformation and post cooling parameters has led to design of cost effective alloys. The sulphur content of the steel was kept below 0.015% followed by CaSi treatment to achieve the desired toughness characteristics. These steels were successfully press formed at the works of major automakers e.g. Telco, Pune and Ashok Leyland, Chennai.

In line with the trend for even higher strength chassis steel for trucks, SAIL has developed a steel grade equivalent to BSK-46 with a minimum yield strength of 450 MPa. The steel chemistry was designed with C: 0.1% maximum, Mn: 1.2% maximum and micro-alloyed with niobium. The steel was controlled rolled in the hot strip mill to achieve the desired properties. The developed steel has been successfully used for manufacturing of chassis frame side members.

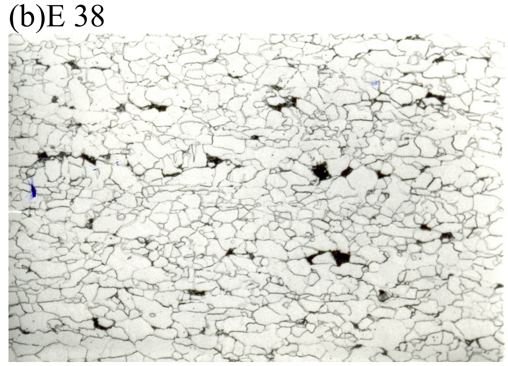
Another grade of auto chassis steel that has been developed by SAIL is equivalent to JISG 3113 (SAPH-45). This grade was being imported to meet the requirement of auto chassis and other structural components of the vehicle. The developed grade has a low yield-to-tensile strength ratio with a minimum yield strength of 310 MPa and a total elongation of 34%.

(a) E 34

(b)E 38



(c) SAPH 45



(d) BSK 46

Figure 1. Microstructure of auto chassis grades from SAIL. Grain size varies between 5-8 microns.

The chemistry and range of mechanical properties of the developed auto chassis grades are given in Table I and Table II, respectively. The microstructures of the different grades are shown in Figure 1 (a-d). The microstructure essentially consists of equiaxed polygonal ferrite grains (4-8 micron) with a pearlite content varying between 6-10%.

Table I. Chemical composition of high strength auto chassis grades from SAIL.

Equivalent Grades	**C**	**Mn**	**Si Max.**	**S max.**	**P max.**	**Al min.**	**Nb**
E-34	0.06-0.08	0.55-0.70	0.05	0.015	0.02	0.02-0.04	0.02-0.04
E-38	0.06-0.08	0. 80-1.00	0.05	0.015	0.02	0.02-0.04	0.03-0.06
BSK-46	0.06-0.08	0.90-1.20	0.05	0.015	0.02	0.02-0.04	0.03-0.06
SAPH-45	0.06-0.08	0.80-1.00	0.05	0.015	0.02	0.02-0.4	0.01-0.03

Table II. Mechanical properties of high strength auto chassis grades from SAIL.

Equivalent Grades	**Ys (MPa), min.**	**UTS (MPa), min.**	**% El. (50 mm GL), min.**
E-34	340	395	27.0
E-38	375	440	25.0
BSK-46	450	490	21.0
SAPH-45	310	440	34.0

Dual Phase and TRIP aided Steel

Dual phase steels have the special feature of low yield strength, continuous yielding behavior, high initial work hardening rate, and good ductility [1]. Because of these properties, dual phase steels are regarded as attractive material, particularly for applications where both formability and strength are required. Dual phase steels have been successfully developed in as hot rolled condition at the BSL and RSP units of SAIL. The alloy chemistry was designed in such a way that conventional rolling finish (~850 °C) and coiling temperatures (~620°C) resulted in the desired ferrite and martensite microstructure at the Rourkela Steel Plant [2]. At BSL, a low coiling temperature (<400 °C) was employed to produce this grade economically in steel alloyed with C-Mn-Si-Cr. The steel has a yield strength of 380 MPa min., a tensile strength of 560 MPa min. and elongation of 25% min.. Several critical components, e.g., wheel discs for cars, spiders for fan blades and assemblies for tractor and scooter components were successfully formed leading to substantial weight reduction. Microstructures of as hot rolled dual phase steel developed by SAIL are shown in Figures 2 and 3. Special etchants have been used to reveal martensite, retained ferrite and transformed ferrite.

Extensive research activities all over the world are taking place to commercialize ultra high strength Transformation Induced Plasticity (TRIP) aided steel with good formability [3]. The alloy has immense potential in the automobile industry regarding fuel economy and safety. Two chemistries microalloyed with vanadium and chromium were designed and processed at RDCIS, SAIL [4] to produce a variation in the amount and morphology of retained austenite. The studies have revealed that the austenite particle size and morphology play a decisive role in controlling the mechanical stability of retained austenite. The stability of the retained austenite was higher in the case of V-steel due to the smaller size (<1 μm) and the morphology of the austenite phase.

The stability of retained austenite under differing conditions of deformation is compared in Figure 4 on a normalized scale based on the data from the experimental steels. An instability factor ‘p’ has been designed [5] to express the stability of retained austenite in these steels. It has been found to be 15 and 8 for Cr and V steel, respectively. The difference in the instability parameters of the two steels has its genesis in the shape and size distribution of retained austenite particles. Figure 5 is the bright field electron image from Cr-steel containing a maximum of retained austenite [6].

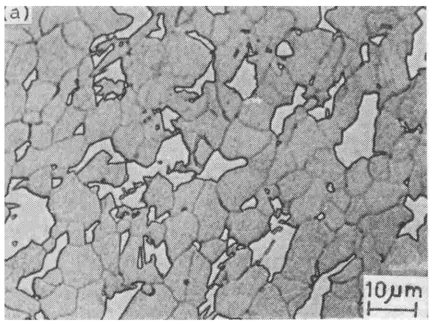


Figure 2. Microstructure of As hot rolled dual phase steel from SAIL, White – martensite

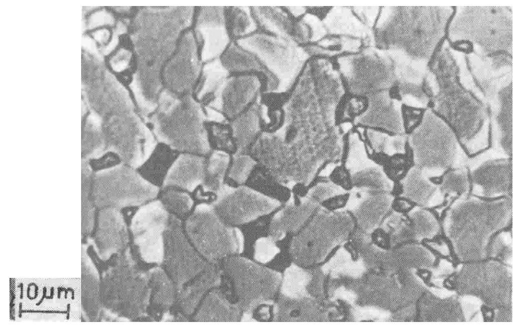


Figure 3. Microstructure of As hot rolled dual phase steel from SAIL, White - transformed ferrite, Gray - retained ferrite, Black - martensite.

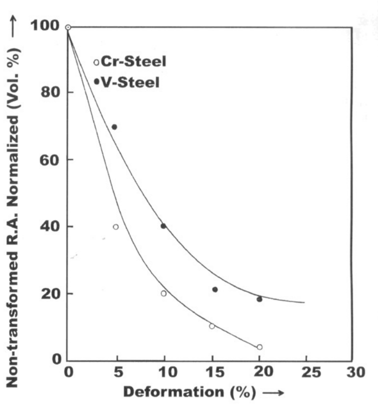


Figure 4. Effect of tensile deformation on normalized volume share of untransformed retained austenite.

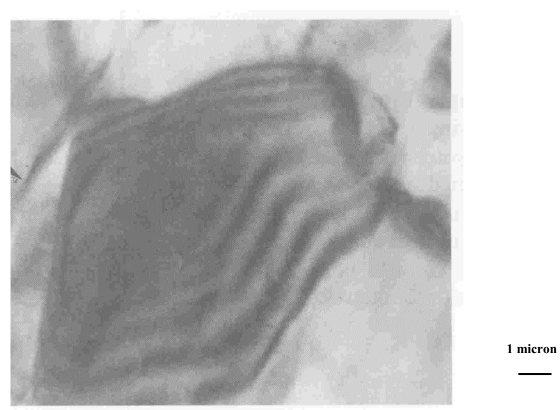
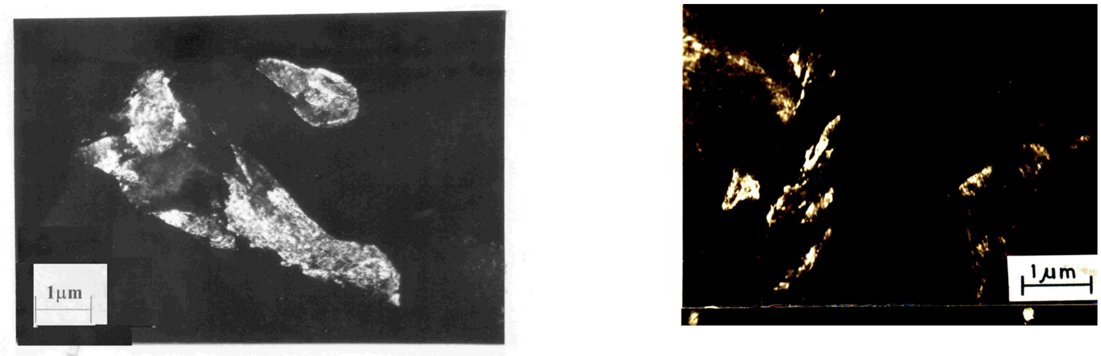


Figure 5. Bright field micrograph of a sample showing the blocky nature of retained austenite.

Figures 6 (a and b) show dark field images of Cr and V-steel of samples thermally cycled to maximize the volume of retained austenite. The figures reveal the film morphology of retained austenite in V-steel. The presence of isolated “tiny particles” of austenite is also evident. Retained austenite particles in Cr steel are in general coarse (2-4 micron) and are interconnected. The particle size and film morphology in V-steel are less susceptible to being transformed thereby, providing greater stability under deformation. The work has proved helpful in developing TRIP aided steel with tensile strength ~900 MPa and total elongation 29%. With the addition of niobium microalloying both the strength and ductility of the TRIP steels are likely to improve as a result of fine grained retained austenite and a program on Nb added TRIP steel has thus been envisaged by RDCIS, SAIL.



(a) Cr-Steel (b) V-steel

Figure 6 (a) and (b). Dark film image from (002) spot of austenite showing blocky retained austenite for Cr steel and tiny and film type retained austenite for V-steel.

High Strength Cold Rolled Steel

High strength cold rolled (HSCR) steels are low-carbon microalloyed aluminum killed steels with increased yield strength and moderate forming capacity. This category of steels owing to their higher strength in comparison to conventional Extra Deep Drawing (EDD) quality steel, favor a substantial amount of material and fuel saving through the application of thinner gauge sheets.

Two grades of high strength cold rolled steel named as HSCR 26 and 35 have been developed by SAIL for automotive applications. The chemistry and properties of these two grades are given in Table III. The plastic anisotropic ratio (r) for HSCR-26 has been found to range from 1.2 to 1.4 and the steel is suitable for moderate forming applications with reduced thickness as compared to conventional deep drawing steels. The components which were successfully formed with HSCR-26 were a rear floor panel and a front floor cross member of a passenger car and a dash panel of a jeep. An auto chassis for a three-wheeler has also been successfully formed with reduced thickness (1.4 mm instead of 1.6 mm).

Table III. Chemistry and properties of high strength cold rolled steel from SAIL.

Grade	**C max.**	**Mn**	**P max.**	**S max.**	**Si max.**	**Al**	**Nb**
HSCR-26	0.08	0.4-0.6	0.02	0.015	0.05	0.02-0.04	0.015-0.03
HSCR-35	0.08	0.8-1.0	0.02	0.015	0.05	0.02-0.04	0.03-0.05

Grade	**YS (MPa) min.**	**UTS (MPa) min.**	**% El. (50 mm GL) min.**	**r**
HSCR-26	260	350	28	1.2-1.4
HSCR-35	350	440	22	-

High strength cold rolled steel with minimum yield strength of 350 MPa is used for household appliances and the equipment segment in India. However, the grade has also potential for forming various structural and safety related parts of automobiles.

A comprehensive understanding was developed on the evolution of microstructure and texture during annealing of Nb bearing high strength cold rolled steel with specific reference to cold rolling and annealing practice [7]. The study aimed at establishing the combination of processing parameters to maximize the r-value in these grades. For a hot rolled microstructure of moderately coarse ferrite (~15 micron), 60% cold reduction was found as an optimum when a high intensity of the (222) component was observed. It was possible to achieve a r-value of 1.5 with optimized annealing practice where step heating at 550 °C for 12 hours was employed.

Ultrafine-Grained Steel

Grain size refinement in steels holds a potential due to the improvement of strength as well as toughness. A 0.013 Nb, C-Mn steel was chosen for developing a fine-grained structure, which can finally lead to a combination of properties suitable for automotive application.

Based on contemporary understanding, a large number of thermomechanical conditions was simulated in the Gleeble 3500C at RDCIS. A narrow window of the thermomechanical processing conditions for the production of ultra fine grains was determined. In these simulations various combinations of deformation temperature, extent of deformation (strain) and strain rate were tried on 8 mm diameter and 12 mm long cylindrical samples. The Ar_3 temperature was determined at a cooling rate of 1 °C/s, which approximately corresponds to air-cooling.

Ferrite grain sizes in the order of 1 to 2 microns were obtained [8] in the surface layers up to a depth of ~0.5 mm in a 3.5 mm thick plate by suitable choice of thermomechanical processing parameters. The thermomechanical processing consisted of soaking at 1250 °C, rolling at ~800 °C in a single pass and water-cooling during rolling. The initial thickness of the plate was 10 mm, which was given a rolling reduction of 65% in a single pass.

The 3.5 mm rolled plate showed a composite microstructure consisting of a core of bainite sandwiched between the surface layers of ultrafine-grained ferrite. Figure 7 shows the optical micrograph of the surface region. Figure 8 shows the scanning electron micrograph of a composite microstructure with ultra fine grain of ferrite (a) and bainite (b) in the interior. It can be observed from these micrographs that the region near the surface consists of extremely fine grains. This plate was found to process very attractive mechanical properties in terms of yield strength (YS), ultimate tensile strength (UTS) and YS/UTS ratio. The YS was found to be ~485 MPa, UTS ~763 MPa and YS/UTS ~0.63. The YS/UTS ratio at this level of YS is particularly very desirable for many applications where high strength level combined with high toughness are required such as structural components of the automobile.

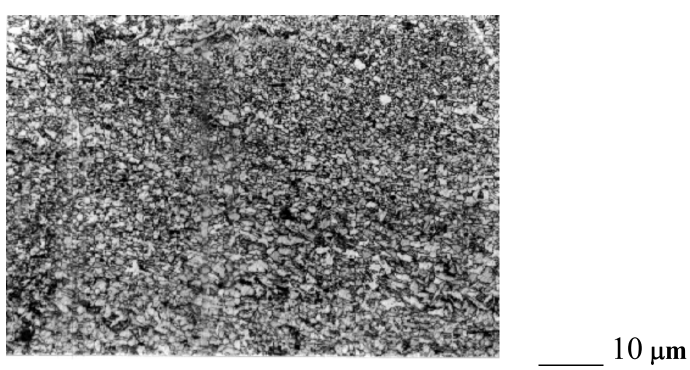
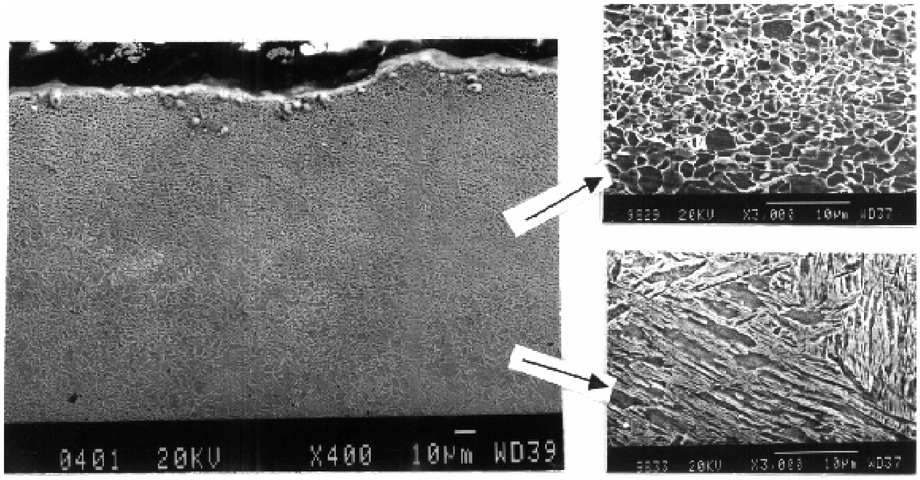


Figure 7. Optical micrograph showing ultra fine grains of ferrite at the surface of the sample.



(a)

(b)

Figure 8. Scanning Electron micrograph showing composite microstructure consisting of ultrafine grains of ferrite in the surface and bainite in the interior.

Conclusions

High strength steel will become increasingly prevalent in the auto industry. SAIL has developed several grades of niobium microalloyed hot and cold rolled steel with improved formability. Ultra fine-grained steel microalloyed with niobium has potential to be used for load bearing components in the automobile.

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