A comparative study on the mechanical properties, and formability of heat treated Dual-Phase DP 600 steel against the conventional SPFH 590 steel

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Abstract. The present work reports a comparative study on the mechanical properties, and the formability of dual-phase DP 600 steel against the conventional SPFH 590 steel which are widely used in automobile industry for its high specific strength properties. In the present study, grain refinement is proposed as an alternative solution to improve the mechanical properties of low alloyed DP steels. To achieve this, severe plastic deformation was applied to pre-processed DP steel by means of conventional cold rolling, followed by an appropriate final heat treatment with the aim to produce a homogeneous fine grained dual phase ferritic-martenistic micro structure. The method used in this work is to increase the tensile strength of dual phase steels by increasing the martensite fraction, by applying appropriate annealing techniques. The heat treated DP 600 steel has good formability compared to conventional steel. DP 600 grade steels under-goes bake hardening which increases yield strength by 55 MPa upon heating and ageing the same 175 °C for 25 minutes. There is an improvement in the “In Field Performance”. Reduced sheet thickness results in reduction in the weight of body and also the cost of the product. The work finds its application in many areas which demand on better formability such as automobile wheel rim, automobile body covers, etc.

Keywords. Dual phase steel, bake hardening, mechanical properties, heat treated, formability.

1. Introduction
The rising demands for reduced fuel consumption in the automobile sectors well as the stringent regulations of environmental pollution norms, especially regarding green-house gas emissions[1], and the demand of reduction of material and financial resources, and the recyclability issues have forced the automotive industry into producing higher fuel-efficient vehicles by weight reduction[2]. The advent of new high strength steels exhibiting both high strength to weight ratio and excellent formability offers the automobile vehicle architecture, fuel economy and cost reduction by weight saving and ease and better manufacturability at low cos.

The presence of carbon atoms at interstitial locations [3] in a ferrite matrix were used to give various desired properties by correct process control. Strengthening mechanisms widely used are solid solution strengthening, precipitation hardening and grain refinement. The formability of such steel with low carbon content is high. Adding alloy elements like vanadium, niobium or titanium in micro levels in the composition, accompanied along with fine precipitates of carbides, and grain refinement leads to even high strength levels and increases the ratio of yield to ultimate tensile strength [4]. To overcome the problem of reduced formability during processing, new types of high strength steels called “Advanced
High Strength Steels” (AHSS) [5] were developed. AHSS steels are multi-phase steels consisting of hard regions of martensite, bainite and / or retained austenite uniformly dispersed in a matrix of ductile ferrite matrix at levels and proportions, sufficient to produce desired mechanical properties.

2. Background
The utilization of advanced high strength steels (AHSS) for automotive body-in-white applications has been steadily increasing over the last few years. “It has been reported that decreasing an average car weight from 1750kg to 1500kg can improve the fuel consumption by up to 2km/l. DP steels [6], with their hard-phase regions of martensite present in a soft phase of ferrite, gives distinct properties such as high strength, low yield-to-tensile strength ratio, high initial work hardening rate, continuous yielding behaviour, bake hardenability, and no room temperature aging effects. These properties mainly depend on the size, volume fraction, distribution and carbon content of the martensite phase” [6]. Compared to conventional high strength steels, and mild steel, the strength of DP steels is significantly greater without any loss of formability. Therefore DP steels allow better flexibility in the design of components, and reduce the thickness considerably, and weight reduction in structural components. The dual phase steels have been widely used in hoods, frame and also in Wheel applications. The different grades of dual phase steels have been used for different applications which provide weight reduction and also flexibility in design.”

3. Method
DP steels are used in various grades to suit different requirements of the parts/ components used in the industry, which are dictated by the desired properties and application environment. This variation of mechanical properties is mainly achieved by controlling the carbon content of the steel. The presence of alloying elements such as chromium, vanadium, molybdenum, nickel, and manganese alter the hardenability of the resultant alloy. Another method to improve the tensile strength of dual phase steels is to increase the martensite fraction by applying appropriate annealing schedules, even though this procedure is followed by an expected loss in formability. In the present study, grain refinement is proposed as an alternative solution to improve the mechanical properties of low alloyed DP steels. To achieve this, severe plastic deformation was applied to pre-processed DP steel by means of conventional cold rolling, followed by an appropriate final heat treatment with the aim to produce a homogeneous fine grained dual phase ferrite-martensite micro structure [7].

“Dual phase steels has a microstructure of soft ferrite and pearlite, and grain boundary iron carbide. Irrespective of the manufacturing process, like rolling, batch or continuous annealing, the cooling method remains the same. DP steels are heated within the inter-critical temperature range which is in the field α + γ of the Fe-C phase diagram”[8]. Subsequently, through rapid cooling, austenite begins to transform to martensite when the temperature reaches the MS temperature. Dual phase steels are characterized by a micro structure consisting of a fine dispersion of hard martensite particles in a continuous soft ductile ferrite matrix. The term dual phase refers to the presence of essentially two phases, ferrite and martensite in the micro structure, although small amounts of bainite, pearlite and retained austenite may also be present. Irrespective of the chemical composition of the alloy, the simplest way to obtain a dual phase ferrite-martensite steel is inter critical annealing of ferrite-pearlite micro structure in the α + γ two phase field, followed by a sufficiently rapid cooling to enable the austenite to martensite transformation.”

4. Experiment
Samples made from Low-C-Si, Med-C-Si and High-C-Si steels were annealed at 775°C for 300s and then quenched in water at room temperature. This heat treatment was designed to produce three different dual phase microstructures with similar martensite carbon contents but with different martensite volume fractions. It is revealed that three dual phase micro-structures are characterized by similar martensite C-contents but exhibit different volume fractions. These three microstructures are designated henceforth as ‘Low-Martensite’, ‘Med-Martensite’ and ‘High-Martensite’ according to their martensite C-content.
The microstructure contains the lowest amount of martensite (~13%), it is designated as ‘Extra-Low-Martensite’ [9]. This micro-structure was developed to assess the high strain rate deformation behaviour of full-martenistic steel [10].

5. Properties, test results and discussions
The spectroscopic analysis of the sample from both conventional steel and dual phase steels was prepared for testing the chemical properties of the material. The conventional steel considered was SPFH 590 grade material and this was compared against dual phase DP steel. The results of the spectro test were shown in the below Table 1 which indicates the element by percentage weight present in the material.

| Element    | SPFH 590 % | Dual Phase % |
|------------|------------|--------------|
| Carbon     | 0.055      | 0.071        |
| Manganese  | 1.330      | 1.330        |
| Silicon    | 0.409      | 0.325        |
| Phosphorous| 0.018      | 0.011        |
| Sulphur    | 0.006      | 0.005        |

6. Microstructure analysis
The microstructure of the conventional steel SPFH 590 and dual phase steels (DP 600) was analysed in a microscope. The DP steel microstructure shows the presence of martensite in the form of islands which is dependent on the carbon content.

The amount of carbon content decides the martensite formation around the ferrite region. The microstructure of conventional steel SPFH 590 grade material is shown in the Figure 1 and that of dual phase steel (DP 600) grade material is shown in Figure 2 showing the presence of ferrite-martensitic microstructure. DP steels are characterized by a microstructure consisting of a finely dispersed particles of hard martensite particles in a matrix of continuous soft ductile ferrite. Thus the presence of two phases namely ferrite and martensite justifies the name Dual Phase.
Figure 3. Stress Strain curve of SPFH 590

Figure 4. Stress Strain curve of DP 600

From the above graph in the Figure 3 and Figure 4 it is clear that the formability is very good in DP steels because of low yield strength. However formability is achieved even in SPFH 590 grade, complex shapes are easily achieved in DP steels grade. To improve the “In Field Performance”, DP600 material is bake hardened. Bake hardening is an advanced processing technique to produce low carbon steels, used for car bodies, with high strength.
Table 2. Mechanical properties comparison

| Property      | SPFH 590 grade | DP 600 grade |
|---------------|----------------|--------------|
| Yield Strength| 550 MPa        | 477 MPa      |
| Tensile Strength | 598 MPa    | 631 MPa      |
| Elongation    | 26%           | 23%          |

The above Table 2 clearly indicates that yield strength of DP 600 grade is low compared to conventional SPFH 590 grade material. Because of this low yield, formability is achieved easily in DP steels than conventional grade. The tensile strength of SPFH 590 grade is 598 MPa and that of DP 600 is 631 MPa. Also the gap is more between yield strength and tensile strength which enable excellent formability. The elongation is 26% in SPFH 590 grade and that in DP steels it is 23%.

7. Applications

In the wheel application, the parts are classified into two major categories namely the Rim and the Disc. The forming trials have been carried out with conventional SPFH 590 grade material and also with DP600 grade material. For trial purpose, we have considered the style wheels which have complicated shapes in the forming stages. The test result after completing the forming has minute cracks in the vent hole area while using the SPFH 590 grade as shown in Figure 5 and the similar trials have been carried out using DP 600 grade which attains good formability as shown in Figure 6.

![Figure 5. Cracks during forming of SPFH 590 grade](image1)

![Figure 6. No-visible cracks formed using DP 600 grade](image2)
8. Conclusions
The DP 600 steel because of its low yield point comparatively gives good formability. Followed by forming, these discs undergo bake hardening of heating the same for nearly 175 °C for 25 minutes improved the yield strength, and thereby achieving “In field performance”.

The major reason for the crack is due to poor forming in the SPFH 590 grade which is mainly due to the high yield strength and less band gap between yield strength and tensile strength. This is overcome in dual phase steel DP 600 which initially starts as low carbon steel or as a medium carbon steel which is subsequently quenched from a temperature above A1, and below A as reflected in the TTT diagram. This results in a microstructure consisting of a soft matrix of ferrite containing islands of second phase hard martensite. The increase in the strength and better formability suggests a decrease in the sheet thickness for the same strength, which results in higher weight reduction, which in-turn results in fuel economy, material utilization reduction and thus reducing the cost of the materials used for the product and the manufacturing cost due to improved formability.

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9. References

[1] Abid Najmul H Abul-Al-Rub Rashid K Palazotto Anthony N 2015 Computational modeling of the effect of equiaxed heterogeneous micro-structures on strength and ductility of Dual Phase steels Computational Material Science. 103 20
[2] Tasan C C Hoefnagels J P M Diehl M Yan D Roters F Raabe D 2014 Strain localization and damage in dual phase steels investigated by coupled in-situ deformation experiments and crystal plasticity simulations International Journal of Plasticity. 63 198
[3] P R Mould and C C Skena 2010 Structure and properties of cold rolled ferrite-martensite (dual phase) steel sheets Proceeding Formable HSLA and Dual phase steels. AIME New York 181
[4] Hsun Hu 1979 Effect of silicon on annealing texture plastic anisotropy and mechanical properties of low carbon phosphorus containing steels Formable HSLA and Dual phase steels. 109
[5] A Okamato and M Takahashi 1981 Control of strength and r-value in box annealed dual phase steel sheet Fundamentals of Dual phase steels. 427
[6] A F Crawley M T Shehata N Pussegoda C M Mitchell and W Rn Tyson 2011 Processing properties and modeling of experimental batch annealed dual phase steels Fundamentals of Dual-Phase Steels Symposium at the 110th AIME Annual Meeting Chicago IL USA Metallurgical Society of AIME Warrendale Pa USA. 181
[7] R G Davies 1981 Tempering of dual phase steels Fundamentals of Dual phase steels 265
[8] J Y Koo and G Thomas 1977 Design of duplex low carbon steels for improved strength weight applications Formable HSLA and Dual phase steels. 40
[9] J W Morrow G Tither and R M Buck 2013 Inter-critically annealed dual phase steels for automotive applications Formable HSLA and Dual phase steels. 151
[10] G Thomas and J Y Koo 1979 Developments in strong ductile duplex ferritic-martenistic steels Structure and properties of Dual Phase steels. 183