

The Impact of Microstructure Tests on the Mechanical Behavior of Press Hardening Steel: A review

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Abstract

Exceptionally strong press-hardened steels (PHS) are significantly demanded in the automobile industry for satisfying the carbon neutrality criterion. Recent research attempts to produce advanced-ultrahigh-strength medium steels have resulted in a variety of alloying approaches, thermomechanical processing techniques, and microstructural modifications for these steel grades. It has been shown that adding microalloying components to standard Mn-B steels can refine the microstructure of PHS which leads to better mechanical properties such as hydrogen embrittlement resistance and other performance indicators for service. In this paper a general review about the effect of microstructure test on the mechanical behavior of Press Hardening Steel (PHS) where microstructure approaches have also demonstrated good potential for the mechanical characteristics of PHS steel, in line with need for new evaluation and discovery meantime, statistical data of the microstructural phases heavily influence the mechanical properties, microstructural image analysis is essential. The purpose of this paper is to know how the microstructure phases will effect on the strength and hardness of press hardening steel also the alloying elements adding impact on the microstructure formulation and mechanical features of PHS.

1. Introduction

As PHS steels were created in the 1980s and have become widely utilized since 2005, it has grown well known that they are utilized extensively in the passive safety of vehicles additionally, since steel and the automobile industries both recognize that human civilization needs a safer world, they are collaborating closely to increase the efficiency of their material production processes [1]. It has been discovered that PHS with grade 22MnB5, when subjected to the hot-pressed process, can combine fair local elasticity with high hardness. This kind of steel is an element of the advanced high strength steel (AHSS) family. The first batch of AHSS had a ferrite microstructure, which was then followed by a second generation which included significant austenite content, and we are at present in the third generation of the steel [2]. In overall, there are two distinct kinds of press hardening techniques for these metals: both direct and indirect. The first technique involves transferring a hot blank to a press for shaping and chilling. The indirect method involves heating a cold-formed blank before transferring it to a cooling tool for final shaping and cooling. The final component has tension strength values ranging from 1500 to 2000 MPa, providing the fabrication of elements that have multiple mechanical features [3]. Due to their low susceptibility to crack development, especially since plastic strain localization develops after a crash, these alloys have shown to have ductile fracture problems in the final portions (like the absorption of energy components). It has been demonstrated that bainitic and martensitic steels exhibit excellent localized ductility

capabilities [4]. This paper presents a general review of the effect of microstructures of PHS steel tests on the mechanical properties as well as the influence of elements alloy on the mechanical properties.

2. Microstructure tests

The microstructural characteristics observed in metallic alloys have a significant influence on the material's mechanical and physical properties. [5, 6]. Microstructure of the press hardening steel depends upon the manufacturing process also on the heat treatment which is done on this steel to improve the mechanical features. In the microstructure tests where they need to be done the surface of the samples must be taken care of utilizing SIC papers then polishing with 3-1mm diamond suspensions and Nital 4% solution etching. Several essential tests can be used [7].

2.1. Scanning electron microscope (SEM)

Scanning electron microscope is a kind of microscopy using electrons that use an electron beam focused on a sample's surface to create images of the sample as shown in Fig. 1. When electrons interact with specimen atoms, they create an array of signals which offer information regarding the composition of the specimen including surface characteristics. The interactions that occur of the beam of electrons via atoms at various thicknesses within the sample provide the signals that a SEM uses to create an image. A variety of signals are generated, such as transmitted electrons, absorbed current

(specimen-current), unique X-rays, light (cathodoluminescence) (CL), reflecting or back-scattered electrons (BSE), and secondary electrons (SE). All SEMs come equipped with secondary electron detectors as standard equipment, however it is uncommon for one device to contain detectors for every other type of signal [8].

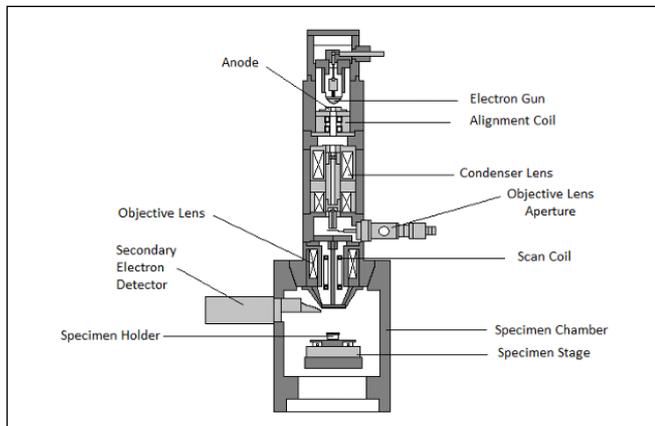


Fig. 1 Scanning electron microscope (SEM) [9].

3. Mechanical tests

There are many important mechanical tests such tensile, bending, hardening, fracture tests and these tests will carry out many mechanical features such that tensile and yield point also the ultimate tensile value and the hardness value.

3.1. Tensile test

An essential test in the fields of materials science and engineering, elastic testing (sometimes called tension testing) includes exposing the specimen to a controlled force till breakdown also optimum stretching, fracture capacity, greatest tensile strength, and area reductions among features that can be precisely established utilizing a tensile examination. Several other features can also be ascertained from these evaluations: strength of yield, modulus of Young, Poisson's percentage, and strain-hardening properties. The most common approach to figure out the mechanical features of materials that are isotropic is uniaxial tensile inspection. Biaxial tensile testing is used for some materials. The way that the materials are loaded on these testing devices varies significantly [10].

3.2. Hardness test

Hardness tests are among the quickest and least expensive ways to define a material's mechanical qualities because they essentially don't ruin the product being tested. There are four different methods for calculating the value of hardness [11].

- Brinell Hardness Testing: Determines toughness by pressing a known weight into an indenter and evaluating the indentation's diameter.
- Rockwell Hardness Testing: gives a rapid readout, mainly for samples made of metal.
- Vickers Hardness Testing: utilize a pyramid of diamonds to create a square impression on the material's surface for examination.
- Knoop Hardness Testing: estimates the hardness of the subsurface.

4. Numerous studies

Although phase changes in 22MnB5 steel have been studied within manufacturing processes, far fewer studies have been done on the impact of microstructure tests on press-hardening steel's mechanical properties. Four types of 22MnB5 were utilized and the initial microstructure was different. Treatment of austenitizing with time of 450s and 180s at temperature 900 °C, were considered as shown in Fig. 2. A mixture of martensite and auto-tempered martensite was found in the microstructure characterization whereby utilizing SEM and optical microstructure tests. Tensile tests with high plastic deformation rates were used. According to the research results, the initially formed microstructure within the 22MnB5 steel determines its strength and uniform elongation. It has been established that parent austenite, which grain size influences the transformed martensite's form, which in turn influences the material's strength and uniform elongation during press hardening [12].

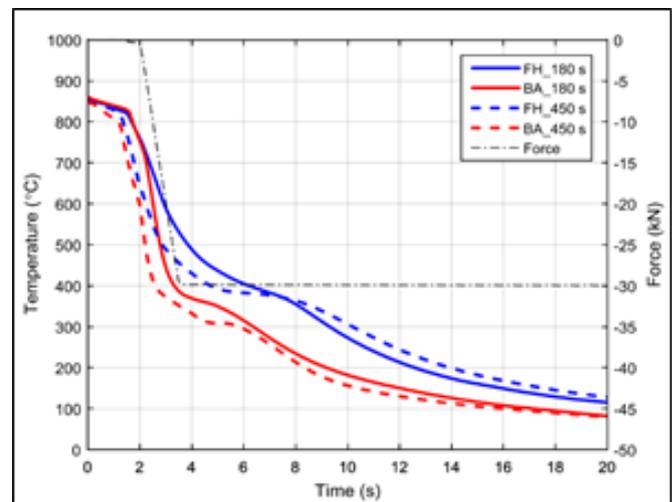


Fig. 2 temperature and pressing force during die-quenching.

Investigated the process's variables, including the cooling rate, soaking period, austenitizing temperature, and beginning deformation temperature. Observations and analyses were conducted on the microstructures of the specimens also tensile and hardness test were concluded to calculate the mechanical properties. It appears that the transformation properties of 22MnB5 steel are altered by heat deformation. To cause a fully martensitic transformation, austenite deformation increases the critical cooling rate and supports the austenite-to-ferrite transformation [13]. Discussed the ability of how cooling rate affected the hardened boron steel's high strain rate behavior. Throughout the solid-state transformation, four rates of cooling were recorded: 250 °C/s for oil quench, 45 °C/S, 25 °C/S for the compressed air quench, and 2200 °C/s for water quench. For each cooling rate, the as-quenched microstructure was verified by optical microscopy and micro-hardness tests. Tensile test was performed at strain rates (0.003 s⁻¹, 960 s⁻¹). The obtained stress vs. strain curves demonstrated that for the specimens chilled at 25 °C/s, the UTS climbed from 1270 MPa to 1430 MPa as the rate of strain increased, whereas for the specimens cooled at 2200 °C/s, the UTS grew from 1615 MPa to 1635 MPa. The results demonstrate that the sample which has been quenched at an elevated rate will have a high level of hardness. The failure mechanism changed from a ductile-shear mechanism at slower rates of cooling to a shearing mechanism

at larger cooling rates, as evidenced by micrographs of the broken specimens [14]. Examined at how the cooling rate affected the hot-stamped boron steel's microstructure and hardness. Sheet heated to 900 °C for four minutes subsequently press produced and concurrently quench water-quenched or die-hardened. The cross-sections of the quenched samples were analyzed using optical and transmission electron microscopy, and their Vickers hardness were measured. The result shows the specimens that were water-quenched and contained lath-martensite were harder than the hot-stamped specimens, which exhibited an auto-tempered martensite microstructure. Even in cases if the cooling rate exceeds the highest critical cooling rate, lowering the cooling rate beyond the Ms temperature considerably lowers the hardness [15].

In accordance with the CCT-diagram show in Fig. 3 which provided by [16], for the whole martensitic transformation to take place in the 22MnB5 grade, a minimum cooling rate greater than 25 °C/s is needed. On the other hand, austenite deformation causes CCT curves to change, which promotes ferrite production at faster cooling rates, accordingly the steel must be water quenched or without heat deformation for the rate of critical cooling to take precedence in terms of the martensite transition.

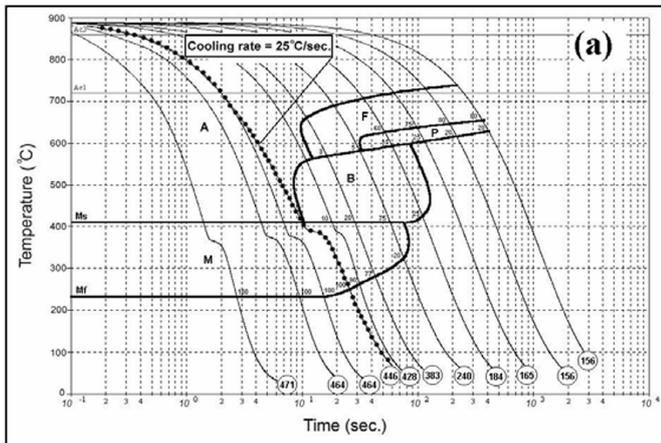


Fig. 3 CCT-diagram for 22MnB5 steel.

Proposed that the reason why hot press steel parts have a higher tensile strength than as-quenched steel parts are because the heat deformation of austenite, which results in martensite's grain refinement [17]. Indicated how phase transition is affected by compressive deformation. After austenitizing, the cylindrical specimen was compressively deformed at 700-800 °C and cooling with the rate from -50 °C/s to ambient temperature. Figure 4 reports the mechanical characteristics of steel at 250 °C.

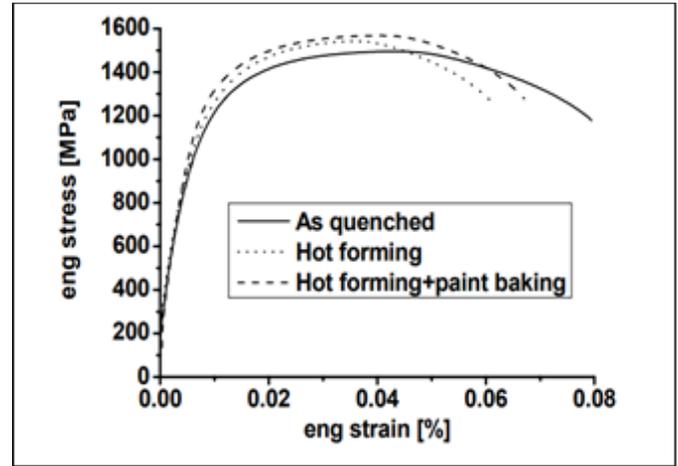


Fig. 4 engineering stress engineering strain curves.

According to this study, the strength significantly decreased, and the ferrite element increased as the plastic strain increased, as well as the plastic strain was significantly higher than with typical martensitic steel grades. To prevent an important decrease of strength he has recommended that the plastic strain be kept minimal and that the temperature at which the deformation occurs should be greater than 800°C [18].

Surveyed how the microstructure of C-Mn high strength hot-rolled steel affected its mechanical properties. The amount of C and Mn contents were adjusted from 0.05 to 0.3% and 0.7 to 1.5%, respectively, to investigate their impact on their mechanical properties. For tensile testing, longitudinal samples were obtained and tested at a cross head speed of 10 mm/mm. Because the step cooling pattern formed a larger volume proportion of polygonal ferrite than a conventional cooling pattern, the steel cooled by the step cool pattern demonstrated the best TS-EI balance during the cooling stage following hot rolling, also the results obtained demonstrated that ferrite-bainite steels exhibited good TS-EI. Increasing the cooling speed also resulted in an increase in TS [19]. It was discovered that the ferrite matrix contains an even distribution of small and fibrous martensite as a result of the intermediate quenching process. In contrast, the martensite and ferrite phases produced by the stage of quenching process are blocky and banded. In summary, intermediate quenching yields a superior blend of strength, ductility, and toughness compared to step quenching [20]. This research effort studied the correlation between bendability and microstructure of ultra-high strength steels (UHSS). Bendability is mostly determined by microstructure uniformity rather than ductility and strength.

Developed a homogeneity index factor through hardness testing also measured hardness to determine the homogeneity index, the homogeneity index was calculated using the Rockwell scale and the standard deviation [21]. In this work indicates partially recrystallized microstructures lead to reduced parent austenite grain sizes in contrast to the fully recrystallized original microstructure of 22MnB5 steel. This leads to greater mechanical qualities, including increased toughness [22]. Investigation offered a simplified approach for achieving excellent ductility in 2000 MPa pressing hardened steels (PHS) by intelligently managing auto-tempering. The new industrial hot stamping procedure generated a 2000 MPa PHS with an impressive mix of high strength, ductility, and toughness without the need for extra tempering. Analyses were

conducted on the mechanical characteristics and microstructure of press-hardening steels as shown in Fig. 5. The result show that reducing the cooling rate below Ms for PHS with a carbon content of 0.36% enabled carbon migration and the creation of nanoscale ϵ -carbides in the martensite matrix, which can improve toughness and ductility without the need for additional tempering [23].

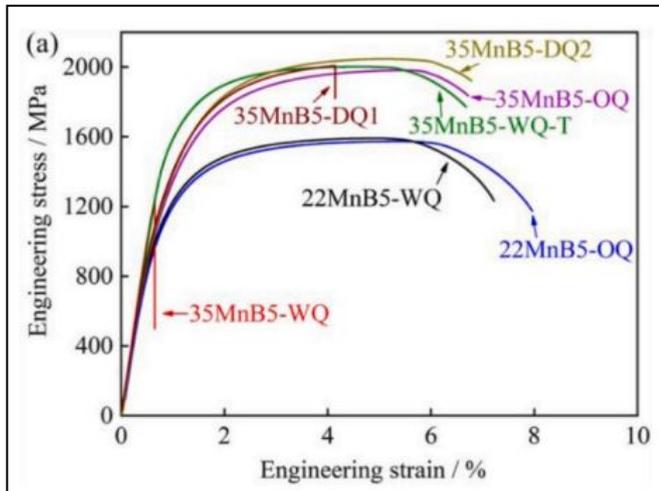


Fig. 5 tensile test result for PHS grade.

In this model develops a mechanism, devoid of any direct strain measurement instrument, for estimating fracture strain of PHS through using discontinuous bending tests and extrapolation. The fracture strain of raw and AlSi-coated PHS with different thicknesses and austenite grain sizes are then calculated using this method, and the outcomes are contrasted with those obtained through direct strain measurements also to evaluate the elements and presumptions influencing the precision of the suggested approach, an error evaluation is also carried out, Fig. 6 microstructure of sample with different thickness. Sheet thickness has a significant influence on the bendability of press-hardened steel plates under plane strain bending conditions, which is generally defined by the maximum bending angle that is determined from the load-displacement curve. For different sheet thicknesses between 1.0 and 2.0 mm, the bare 22MnB5 steel's fracture strain was 0.29 [24].

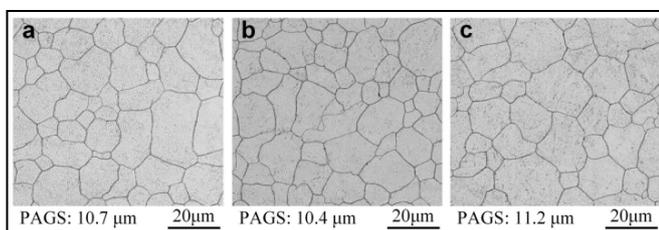


Fig. 6 micrographs showing prior austenite grain boundaries of 22MnB5 steel specimens after press hardening. (a) t1.0, (b) t1.5, and (c) t2.

This work explains how the microstructure affects hot stamped boron steel's fracture toughness. Different microstructures are created by a heat treatment procedure, most of which are just a single phase or composite microstructures with two separate phases also the fundamental work of fracture approach is used to assess the fracture resistance of the current microstructures. The results indicate a significant relationship among fracture toughness and

microstructure. Although a combined microstructure of a bainite and martensite demonstrates an extremely brittle fracture behavior, the bainitic grade demonstrates good fracture toughness [25]. This approach in this model recognized the effect of a standard paint baking procedure on the characteristics of press-hardened boron steels. Analyses were conducted on the impact of steel carbon amount and austenite grain size prior to bake hardening on the mechanical properties of the treated steels. The present results show how the bake hardening behaviour of steels that have been press-hardened was influenced by additional alloying components in addition to preceding austenite, which size of grains and carbon concentration. Further research indicates that baking enhances the ductile fracture behavior and post-uniform elongation of 34MnB5, but has no discernible effect on the ductile fracture mechanisms of 22MnB5 and 30MnB5, which correspond to lower strength levels [26]. Prepared assessment of the mechanical characteristics and microstructure of various high-strength carbon steels upon hot stamping. Waters as well as nitrogen cooling media were used to hot stamp four exceptionally strong non-boron alloyed steels on the hot stamped samples, microstructural tests, laterally and surface hardness profiling, and tensile testing were carried out. The result show that maximum strength and a mostly martensitic microstructure were achieved by increasing cooling rates, i.e., through the use of the nitrogen chilled punching (NCP) during hot stamping however, because there was some ferrite phase present, hot stamping with a water-cooled punch (WCP) produced the highest formability index possible [27]. This study examined the impact of remaining austenite on a new press-hardened steel's fracture characteristics also by adjusting the die contact pressure throughout the press hardening process, martensite auto-tempering was tuned to produce retained austenite with varying degrees of mechanical equilibrium however the ideal blend of tensile plus bending characteristics is offered by mechanically stable retained austenite. When bending beneath localized plane strain and strain gradients conditions, the unstable retained austenite can rapidly transition into brittle martensite, as opposed to tensile testing when uniaxial stress occurs which encouraging the beginning and propagation of cracks [28]. In this analysis of the ultrahigh-strength martensitic press-hardened steel's resistance to fracture also double-edge notches tensile (DENT) and uniaxial tensile tests were used to evaluate the fracture capabilities of a novel PHS alloy, The fracture strain and fracture work describe the fracture resistance under uniaxial force. Even though there is a large number of grain boundaries, the material exhibits a great resistance to damage nucleation, which is responsible for the massive fracture strain. CrSi-PHS possesses fracture toughness parameters that are similar to multiphase AHSSs with weakened strength levels but lower than those of the commercial PHS 22MnB5. The discontinuous propagation of the crack is caused by the merging of micro-cracks and the ductile fracturing of micro-ligaments. In overall ultrahigh-strength martensitic steels, the observations show an important impact of the fracturing mechanism and resistance to fracture on the loading situation [29]. The influence for retained austenite on AISI 4330 Lower Alloy Steel's Microstructure as well as Micro-Hardness Employing by the X-Ray diffraction technique. The specimens were heated to 800, 900, and 1000 degrees Celsius and cooled at various rates using water and oil. The results show that for the same quenching media, retained Austenite production

increases as heating austenitizing temperatures and cooling speeds grow. The findings indicate that when heating temperatures increase, hardness evaluations decline [30].

5. Influence of alloying elements on mechanical and microstructural features of PHS

Press Hardening (PH) steels' mechanical and microstructural characteristics can be significantly influenced by alloying components. It is well recognized that certain elements, including as Ti, Nb, Cr, Mo, and La, have an impact on precipitating in turn affects the mechanical properties of steel [31], during thermomechanical operations, microalloying elements like tantalum and niobium can precipitate in austenite, increasing mechanical characteristics through refinement of grains and precipitation hardening. The hardness and corrosion resistance of the steel can be impacted by the addition of metals like Cr and Mo [32], which can lower the amount of carbon in austenite and encourage nano-sized forms precipitates in the ferrite matrix [33]. Adding ideal amounts of Si and Cr to the new PHS which will be developed at the industrial scale without changing up hot forming technique. The result demonstrated that the new PHS's uniform as well as post-uniform elongation were both improved by the RA and exhibiting an exceptional 9.2% overall elongation with an exceptionally high 1680 MPa tensile strength as shown in Fig. 7 [34].

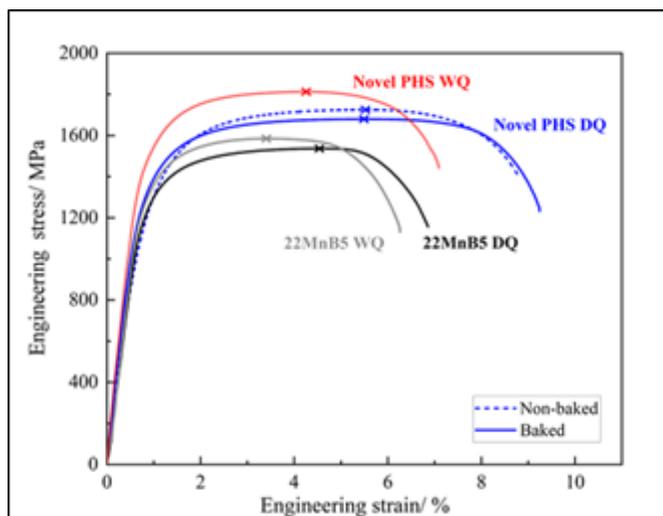


Fig. 7 Engineering stress-strain curves of the novel PHS and 22MnB5 samples after the DQ and WQ.

The Q and P procedure using incorporated continuous deformation and optimized it for the 42SiCr and 42SiMn high-strength steels, each having 0.43% C. The outcomes imply that the mechanical properties are significantly impacted by the addition of Cr [35]. The roles of Ti and V in conjunction using Cr or Mo established five steels with a 34MnB5 base also, using advanced imaging techniques, the correlations between microstructure and properties were examined following die-quenching and further baking hardening (BH) heat treatment [36]. The effect of niobium element on the enhanced mechanical properties such that crash performance for alloyed press hardening steel have been rigorized. Press hardening steel raises serious concerns about hydrogen embrittlement because earlier research showed that a small amount of hydrogen (a few parts per million) could cause delayed cracking. Nb microalloying is an effective way to refine the

microstructure of high strength steel, which has been shown to be a generally effective method of increasing resistance against brittle failure [37]. New model of steel alloy material which involve study the Impact of co-adding on future generation's mechanical and microstructural characteristics 3Cr-3W and 5Cr-3W. Novel low-carbon steels made by hot rolling and casting. The samples completed one hour of annealing at 1100 C, one hour of air quenching, and two hours of tempering at 710 °C [38]. The effect TiN-particles on the fracturing of components and sheets of press-hardened steel has been investigated. It is well known that big TiN particles weaken high-strength steels' toughness. Also, a quantitative examination is conducted on the form and distribution of TiN particulates for two 22MnB5 PHS sheets with nitrogen contents of 29 ppm and 44 ppm in mass [39]. The study of adding boron hardenability in direct-quenched thermomechanical processes steels with nominal contents in 0.2C-0.6Mn-0.5Mo were concluded. These steels experienced hot rolling in a manner similar to production multi-pass rolling, and the behavior of their transformation underwent subsequent water quenching at varying temperatures for finish rolling [40]. Investigation about the effect of Al-alloyed press-hardening steel with superior mechanical and antioxidant properties, ferrite-component forming whereby adding the Al and limit the growth of cementite and improve the stability of austenite also improves the stability of recovered austenite (RA), Al can produce thick Al oxides near the bottom of oxide layer, leading in the better antioxidant capabilities [41]. Experimental model employing the four-point bending test as well as the standard strain rate tensile test (CSRT), the influence of the alloying components on the hydrogen embrittlement characteristics of ultra-high exceptionally strong low alloy evolution caused plasticity (TRIP)-aided steels that have a martensite matrix (TM steels) had been examined. The alloying addition enhanced the TM steels' hydrogen embrittlement capabilities [42]. The metal such as Ni content affected the PHS laser welded joints' hardness, strength, and microstructure. Studies have demonstrated that Ni enhanced the transition from the δ phase to the γ phase and decreased the amount of solidified main δ phases in the fusion zone [43]. The influence of alloying element addition on mechanical characteristics and carbide precipitation in martensitic steels with 5% chromium were carried out. The primary objective was to move the second hardening peak in the direction of increasing tempering temperatures. Furthermore, the mechanical characteristics demonstrated that, while having a negative impact on Charpy impact energy, the volume fraction of tiny forms precipitates (VC, Fe₃Mo₃C) significantly impacts the mechanical resistance at elevated temperatures [44]. The oxidation and mechanical properties of 22MnB5 steel with Cr- as well as Si-alloyed press-hardened steel at different heating temperatures (Heated temperatures vary between 750 to 950 degrees Celsius) have been studied. Press hardening steel combined with high Cr and Si exhibit potential in boosting oxidation resistance when compared to ordinary 22MnB5 steel [45]. Using electron transmission microscopy as well as Charpy impact testing, how microstructural changes occur through thermally aging at 823-973 K and its impact on the toughness were examined for ordinary Cr-W and Cr-V steels [46]. This experimental work employed two of Cr-Mo-V steels' uniaxial deformation and fracturing characteristics which 3Cr-1Mo class and a martensitic stainless steel that is plainly tempered and contains

12% Cr. Tensile test were used to characterize the deformation characteristics of the two steels over a broad range of strain rates and temperatures, ranging from 25 to 600°C [47]. The conducted research on steels with varying niobium concentrations for rolling and quenching process. It was discovered that niobium can effectively delay recrystallization and achieve grain refinement [48]. Investigate the influence of Nb and Mo alloying on the capacity to resist to embrittlement of hydrogen for 1.9 GPa-grade hot-stamping steels. Slowly strain-rate tension (SSRT) tests took place before and after hydrogen charge [49]. Explored the impact of vanadium on the hydrogen embrittlement sensitivity of high-strength hot-stamped steel (30MnB5). The impacts of hot-stamped steel on Hydrogen-based embrittlement (HE) was investigated using a hydrogen permeation technique and a pre-charged hydrogen slower rate of strain test [50]. The experimental work concern about the adding 1-3 weight percent copper to a combination (ferrite austenite) lighter steel (Fe-0.8C-15Mn-7Al, in weight percent) which found it was increased H-resistance [51]. The austenite percentage in every sample was a function to the tension strain as well as verified that the mechanical strength of austenite within the high-Al steel was greater than the low-Al steel [52]. It has been noticed by [53] that the frequency of the presence of Cr and Ni components is up to more than 90%. Specifically, practically every typical high-strength stainless steel includes Cr and Ni to satisfy the criteria of superior strength and anti-corrosion qualities. It is known whereby [54] that Si and Nb elements found in stainless steel can serve as solution as well as grain refining strengthening employees, accordingly, The Nb element will enhance the martensitic microstructure, decrease the spread of fractures, and improve the stress-induced cracking resistance of steels. Alongside with investigation the role of Si in boosting both the stability of remaining austenite and the mechanical features for two medium carbon bainitic steel [55]. This work focusses on the influence of Mn-segregation-induced TRIP mechanism in medium-Mn duplex steels to achieve exceptional mechanical features. Austenite produced coarsely in the Mn-rich band caused transformation-induced plasticity (TRIP) with greater efficiency than austenite delicately transformed from martensite in the Mn-lean band. The Mn content had a greater influence on austenite stabilization than the austenite size this leads to in continuous TRIP in the austenite, which of the Mn-rich band [56]. The alloying element such as Ti was adding to know the Impact on the microstructure and Strengths of Press Hardening Steels. Ti adding improves martensite packet, block, and lath, in addition to the prior to austenite grains [57].

6. Conclusions

1. Satisfy the growing need for lightweight materials, one important innovation feature in PHS is an excellent marriage of strength and ductility. This allows for a reasonable optimization of both composition and procedure, subject to financial limitations. High strength, exceptional ductility, and toughness PHS materials have become more common in recent years, as noted in the study.
2. After hot rolling, steel with a step cooling pattern had better TS-El balance due to the development of more polygonal ferrite compared to a common cooling layout.
3. Adding process of Co to the steel result in ferrite and bainite phases. For a certain extent, the appearance of Co

led to the rise in mechanical characteristics also, Co has a consequence of decreasing toughness.

4. Both Ti and V were used to achieve previous austenite grain size (PAGS) refinement; however, micro alloying with Ti produced a more effective refining benefit. But it was found that the PAGS is controlled by the initial microstructure, and this should be considered in steels based on 34MnB5.
5. When adding the Al element to the PHS this will result in limit the growth of cementite and improve the stability of austenite with the stability of recovered austenite (RA) also increases the extension and bending strength of the new PHS.

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