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FROM THE ALLOY DESIGN TO THE MICROSTRUCTURAL AND MECHANICAL PROPERTIES OF MEDIUM MANGANESE STEELS OF THE THIRD GENERATION OF ADVANCED HIGH STRENGTH STEELS

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Abstract

The automotive industry is facing increasing pressure to reduce vehicle weight, enhance safety, and lower production costs while at the same time complying with stricter environmental regulations. Various solutions have been developed to effeciently respond to these conflicting requirements. One promising solution is the development of new steel types of the third-generation of advanced high-strength steels (3GAHSS).These steels aim to bridge the gap between TWIP and TRIP steels. The so-called (MM) medium manganese steels combine exceptional strength, good malleability and lower production costs due to the reduced use of alloying elements such as manganese (less than 12wt. %). Medium-Mn steel is drawing more attention to be designed for future vehicle bodies and structures. Therefore, this paper aims to explore the relationship between chemical composition, microstructure, manufacturing processes, and mechanical properties of medium Mn steels.

Keywords: *Medium Mn steels; Intercritical annealing; Retained austenite; Microstructure; Thermo-mechanical processing*

1. Introduction

The automotive industry faces the challenge of improving fuel efficiency and safety without increasing costs. For more than twenty years, car manufacturers worldwide have been continuously researching the selection of materials to reduce vehicle weight, minimize fuel consumption, and subsequently reduce CO_2 emissions [1-6]. To meet these requirements, car manufacturers are constrained to use the most innovative solutions in terms of materials and design. Car body in white (BIW) and many other parts of vehicles are made of different materials. Hence there are two strategies for vehicle weight reduction: (i) use permanently improved steel solutions; (ii) use alternative materials such as aluminum, magnesium, plastics, and others [6, 7]. Steels have the lowest environmental impact during production compared to other materials used for car bodies and is also easy to recycle due to their magnetic properties, making them a sustainable choice for the automotive industry. For all these reasons steels remain very attractive and functional material choice for car manufacturing because they offer a variety of mechanical properties and are affordable to produce. Continuous research and development in steel technology is crucial for the automotive industry [4]. For many years, steel researchers have been working on the first generation of Advanced High Strength Steels (AHSS) which include the following grades : Dual Phase (DP), Transformation Induced Plasticity (TRIP), Complex Phase (CP) and Martensitic steels. Then, the Twinning Induced Plasticity (TWIP) steels, Al-alloyed lightweight steels with induced plasticity (L-IP) and Shear band strengthened steels (SIP) were discovered and investigated as the second generation of AHSS. However, the high alloying costs, the difficulty in manufacturing process, susceptibility to delayed fracture after forming and the relatively low yield strength all limit the immediate commercialization of the second generation steels [1, 3, 8, 9, 10].

This leads to an increased interest in the development of the third generation of AHSS because they show a similar trade-off between strength and ductility as the second generation but have lower alloying cost and less difficulty on manufacturing. Most of the third generation steels developed are

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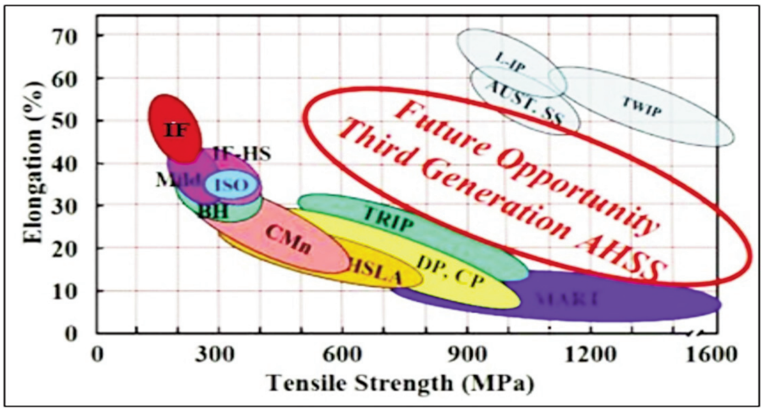

Figure 1. *Schematic representation of tensile strength/total elongation balance for different already developed and future steels [6]*

multi-phased, such as quenching and partitioning processed (Q&P), carbide free bainite (CFB), annealed martensite matrix (AMM) and medium Mn (MMS) steels [8, 9, 11, 12].

Medium Mn steels with a Mn content in the range of 3% to 12 wt% are a promising solution for obtaining high strength steels with good formability at lower alloying costs. This is primarily due to the enhanced TRIP effect, which results from a higher proportion of retained austenite with proper mechanic stability than the retained austenite in the classic TRIP steels. Recently many intensive efforts have led to considerable progress in the development of medium Mn steels [6], [9-14]. A steel's formability, often measured by its energy absorption capacity, can be compared by multiplying its ultimate tensile strength (UTS) and total elongation (TE), resulting in a value known as PSE. Based on this PSE value, Advanced High Strength Steels (AHSS) are categorized into three generations (Fig. 1): first, second, and third. Figure 1 represents the relative positions of these generations. The first generation of advanced High Strength Steels (AHSS) is characterized by a product of strength and elongation (PSE) of 15 GPa%. These steels typically have a strength exceeding 800 MPa but limited elongation (less than 20%).while The second generation of AHSS has a PSE greater than 60 GPa%. The third generation of advanced High Strength Steels (AHSS) exhibits a PSE value between 15 and 60 GPa%. In particular, our research is focused on the review of new designed medium Mn steels. Medium Mn steels with Mn percentage in the range of 3% to 12 wt% is a promising solution to get high strength steels with good formability at lower alloying cost. This is primarily due to the enhanced TRIP effect resulted from a larger fraction of retained austenite with proper mechanical stability than the retained austenite in the classical TRIP steels. Recently many intensive efforts have led to significant progress in the development of medium Mn steels. Fig. 2 summarizes the tensile properties of medium Mn steels that have been reported previously [13-18]. These data scatter in a wide range as they are just

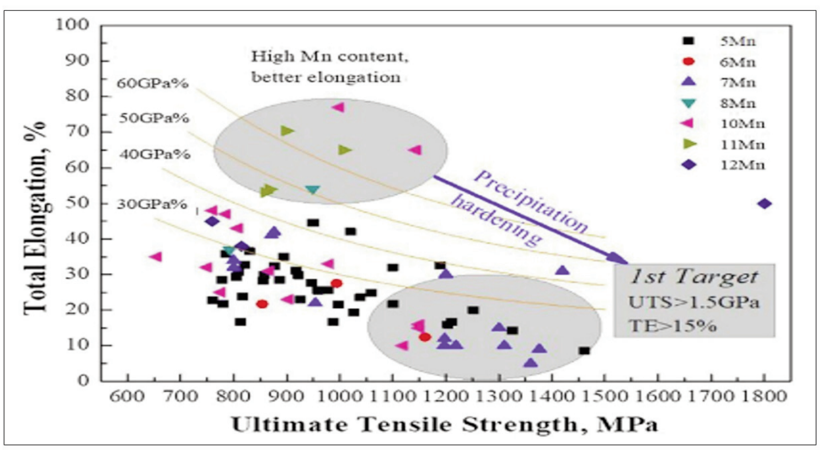

Figure 2. *Summary of tensile properties of medium Mn steels recently developed [6]*

simply classified according to the Mn content.

The mechanical properties of Medium Mn steels are very attractive, but there is a certain amount of unanswered question about microstructure formation, mechanical behavior and the link between these two properties, as well as the effect of processing routes and heat treatment on microstructure and mechanical properties.

Figure 3. *Warm stamped B-pillars from medium-Mn steel recently developed [6]*

Chang et al [12] introduced a warm stamping process for forming the B-pillar of a prototype car using medium-Mn steel at temperatures between 400°C and 700°C, optimized for optimal process parameters. Fully austenitized steel blanks were transferred to a high-speed hydraulic press and formed using a die with internal water-cooling channels. The parts were then quenched under constant holding pressure to achieve a fully martensitic microstructure. Notably, the medium-Mn parts exhibited uniform ultrafine morphologies throughout, regardless of whether the area was tension-dominated or compression-dominated. These steels exhibit exceptional strength-to-weight ratios, often surpassing conventional steels, this is due to the formation of a unique multiphase microstructure composed of ferrite, bainite and retained austenite, which provide a balance of strength and toughness.

Therefore, this review focuses specifically on the relationship between the chemical composition, the manufacturing process, the multiphase microstructure, and the mechanical properties of medium-Mn steels. The aim is to provide a comprehensive overview of how these factors influence the final properties of the steel. And by examining these factors and their interactions, the review aims to provide a deeper understanding of the underlying mechanisms that govern the behavior of medium-Mn steels. This knowledge can be valuable for developing new and improved steel alloys with tailored properties.

2. Medium Mn Steels

2.1. Chemical Composition

Medium Manganese (MM) steels are characterized by a manganese content of 3 to 10% and a complex microstructure consisting of ferrite, retained austenite, bainite, martensite, and small amounts of carbides. Although the concept of MM steels was first proposed by R.L. Miller in 1972 [20], it was not until 2007 that M.J. Merwin [21] reignited interest in these steels by refining the alloy composition for batch annealing processes. It was after Merwin's work that various studies based on the medium Mn concept were accelerated. At the beginning, most of the studies focused on batch annealing using the simple Mn-C alloying system [14], [18]. Some of them focused on understanding the effects of intercritical annealing conditions and alloying elements on the mechanical properties of these steels [22]. Carbon, manganese, silicon, and aluminum are the primary alloying elements found in most medium manganese steels [6]. Table 1 gives an overview of the typical ranges of these elements and their corresponding effects on the steel.

Microalloying elements like vanadium (V) and niobium (Nb) can be added to medium manganese (MM) steels to improve precipitation hardening and achieve sufficient ductility (more than 15%) [6]. For instance, Hu et al [34] observed an increase in yield strength in an Fe-0.2C-6.5Mn-3Al-0.1V MM steel due to VC precipitation within the delta-ferrite phase after intercritical annealing. Similarly, Cai et al [35] developed an Fe-6.5Mn-1.1Al-0.17C MM steel with 0.22 wt% Mo and 0.05 wt% Nb, achieving an ultimate tensile strength of 1224 MPa and an elongation of 33%. This exceptional performance was attributed to their innovative microalloying strategy using molybdenum and niobium, which influenced the austenite volume fraction and stability. S. Yan et al [36] discovered that the addition copper and nickel to medium manganese steel not only increases the amount of retained austenite but also promotes the formation of numerous annealing twins during the annealing process. These twins contribute to breaking down and refining the austenite grains, leading to a significant increase in tensile strength of approximately 90-150 MPa.

2.2. Microstructural properties

Generally, Medium Mn steels are characterized by a composite-like microstructure, while depending on the chemical composition and the processing routes, the final microstructure may be or ferrite martensite duplex phase (FMDP) as that

Table 1. *Alloying elements effects in Medium Mn steels*

Alloying element	Effect
C	- Austenite stabilizer, the usual carbon content in medium
	- Mn steels is in the range of 0.1-0.6 wt.% ; [6]
	- Increases the stability of the retained austenite; [23]
	- Increases the stacking fault energy; [24]
	- Higher C content may led to poor weldability; [9]
	- Higher C can cause severe carbon segregation during casting; [10], [25]
Mn	- As austenite stabilizer, the usual Manganese content in medium
	- Mn steels is in the range of 3 to 10 wt.%; [26], [27]
	- At lower Mn content, low fraction of austenite retained and higher fraction of martensite are formed after intercritical annealing; [23]
	- High percentage of Mn in the retained austenite (RA) increases its stability; [28]
	- Decreases the stacking fault energy; [23]
Al	- Ferrite stabilizer, its concentration in medium Mn steels must not exceed 3wt.%; [6]
	- Inhibits the precipitation of cementite through increasing the carbides nucleation temperature; [14]
	- Excessive addition of Al leads to the formation of delta ferrite phase during solidification; [26], [29]
	- Improves weldability; [6]
	- Increases the stacking fault energy; [2], [30], [31]
Si	- Ferrite stabilizer, added in medium Mn steels with content less than 3wt.%; [2], [6], [24]
	- More than 3 wt.% Si addition can lead to the formation of a large fraction of δ-ferrite which remained coarse even after intercritical annealing; [32]
	- Leads to increased activity of C in ferrite, as well as makes carbon atoms can only be partitioned into austenite during intercritical annealing; [33]
	- Improves weldablity; [6]
	- Decreases the stacking fault energy; [2], [30]
	- The excessive addition of Si may affect the surface quality and cause some difficulties in continuous casting, welding, surface coating and galvanizing; [6]

can be seen in the case of Dual Phase (DP) steels [37], [38], Ferrite Austenite Duplex Phase (FADP) [39], or a mixture of these two types. In the case of the FADP microstructure type, the ultra fine grained (UFG) ferrite acts as a matrix, with finely dispersed retained austenite (RA) islands. The volume fraction, size, morphology and stability of the retained austenite phase affect differently the final properties of these steels [40, 41, 42] it's the stacking fault energy is a main parameter that controlls the mode of deformation. It can change due to the partitioning of alloying elements during intercritical annealing, with C and Mn (austenite stabilizers) passing into the austenite and Al and Si (ferrite stabilizers) passing into the ferrite [43] as described in Fig. 4.

The behavior of austenite grains during deformation depends on the stacking fault energy. In steels with low stacking fault energy, only transformation-induced plasticity (TRIP) occurs (Fig.4-I). However, in steels with medium stacking fault energy (Fig.4-II), both mechanical twinning (TWIP) and TRIP effects occur sequentially. Initially, twinning begins, followed by TRIP at twin boundaries as twinning progresses [44]. This combined effect of TWIP and TRIP enhances work hardening and ductility. Based on manganese content, medium manganese steels can be categorized into low and high manganese types, as summarized in Table 2.

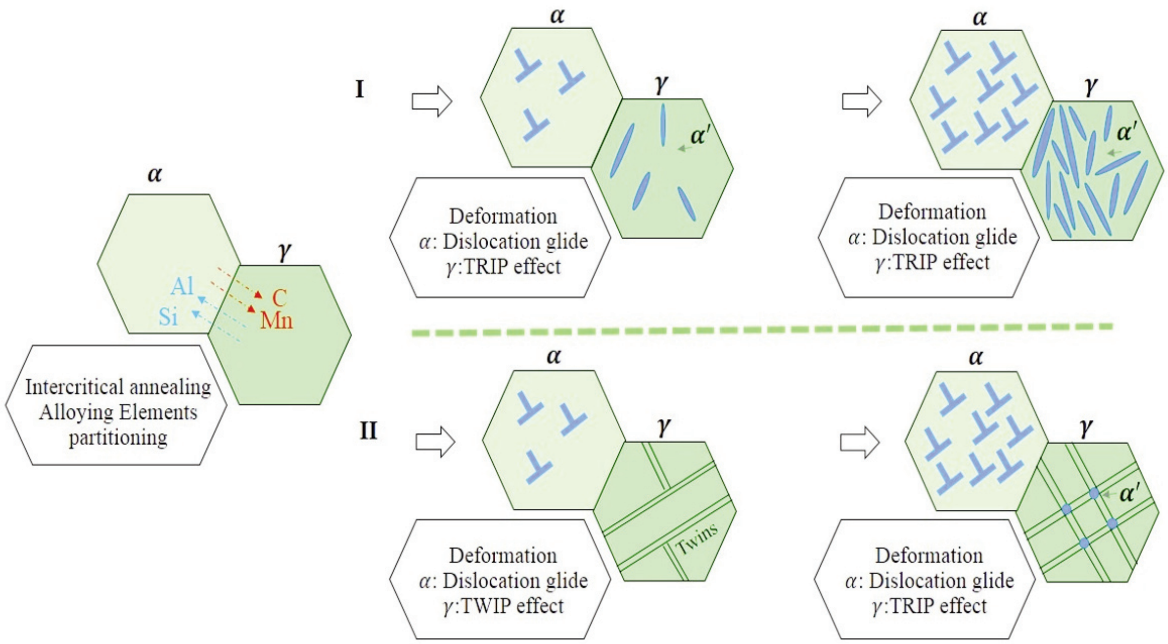

Figure 4. *Schematic illustration of alloying elements partitioning taking place during intercritical annealing heat treatment [44]*

Table 2. *Overview of the main properties of the different types of medium Mn steels [45]*

	Medium Mn (MM)	
Category	High Mn	Low Mn
Wt.% of Mn	12-8	3-7
Applied Heat treatment	Intercritical annealing	
Cold rolled	Deformed α'	
After annealing	UFG $\gamma + \alpha + \alpha$'	
Plasticity	TWIP + TRIP	TRIP
$\gamma_{isf}\left(mJ/m^2\right)$	$15 < \gamma_{isf} < 45$	$\gamma_{isf} < 15$
RA-stability	Depends on the chemical composition, size and morphology of RA	

3. Heat treatment conditions effect

Numerous studies [6], [45-49] have shown that intercritical annealing is a common method for producing medium manganese steels with high levels of retained austenite**.** Factors such as the specific alloying elements used [14, 33, 51, 52], the steel's initial structure , and the exact heat treatment conditions including heating and cooling rates [47, 53], holding times [47, 54], and annealing temperatures [55] can significantly influence the final microstructure of the steel.

3.1. Initial microstructure effect

The initial microstructure significantly influences how medium manganese steel changes during annealing. Particularly, the comparison between hot-rolled and cold-rolled steels after intercritical annealing reveals distinct differences. As shown in Fig. 5, hot-rolled steel, which initially has a fully $\alpha_f^{'}$ martensitic structure, transforms into a mixture of lath-shaped ferrite α and austenite γ_R after annealing. In contrast, cold-rolled steel with a deformed martensitic structure transformed into a microstructure containing globular ferrite and austenite after intercritical annealing. This observation aligns with the findings of J. Han et al [56] who compared the microstructures of intercritically annealed hot-rolled and cold-rolled Fe-9Mn-0.05C medium manganese steel. Their results showed a similar pattern of microstructural evolution. In the same scope, Xuan Li et al [57] observed a fine-

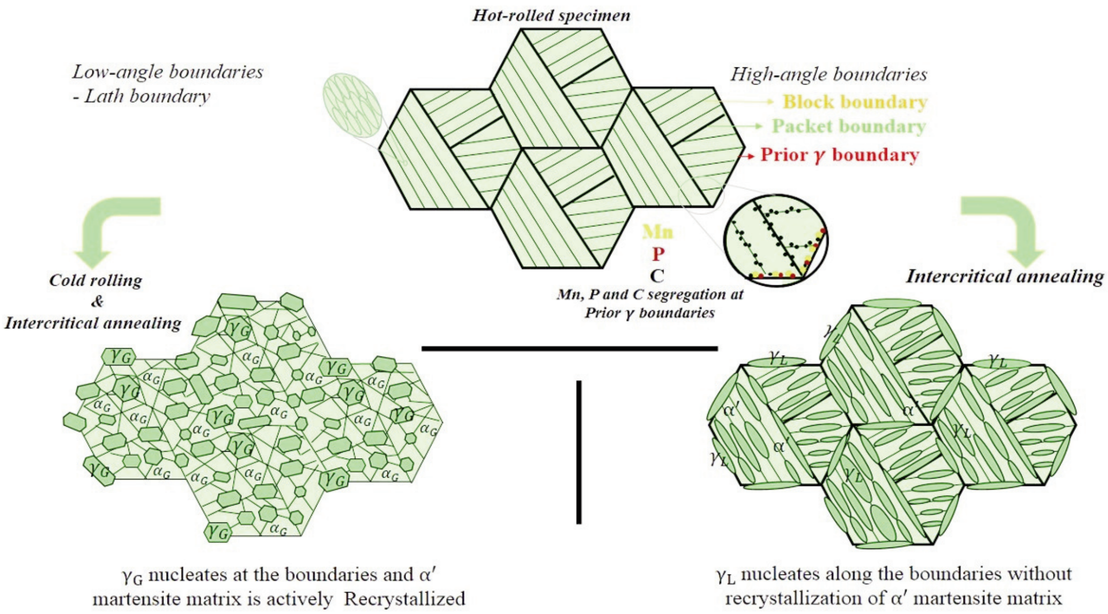

Figure 5. *Schematical sketch of the difference between the cold and hot rolled specimens after intercritical annealing [58]*

grained, mixed structure of lamellar and equiaxed ferrite and austenite (40.5%) after intercritically annealing a cold-rolled Fe-7.75Mn-2.78Al-0.52C medium manganese steel. This microstructure resulted from a combination of ferrite recrystallization and the reverse transformation of austenite.

R. Zhang et al [59] introduced a new processing method for medium manganese steel (0.2C-5Mn wt.%). This process involves an initial intercritical annealing followed by intercritical rolling at 650°C, resulting in a fine-grained, dual-phase microstructure with elongated ferrite and austenite grains aligned parallel to the rolling direction.

3.2. Heating rate

The rate at which a medium manganese steel is heated to its intercritical temperature significantly influences its final microstructure by affecting cementite formation and the stability of the reformed austenite. Han et al [60] studied this by comparing steels heated rapidly (diffusionless: Stage I in Fig.6) versus that slowly heated (diffusive: Stage II in Fig. 6) to the intercritical temperature, The transition heating rate was approximately 15 °C/s. T_θ is the start temperature of cementite precipitation, and As and Af are the start and finish temperatures of the reverse transformation, respectively.

Their results revealed that rapidly heated steel contained lath-shaped retained austenite with many dislocations, while slowly heated steel had a more globular austenite with fewer dislocations. This difference is attributed to the lower chemical stability of the rapidly formed austenite.

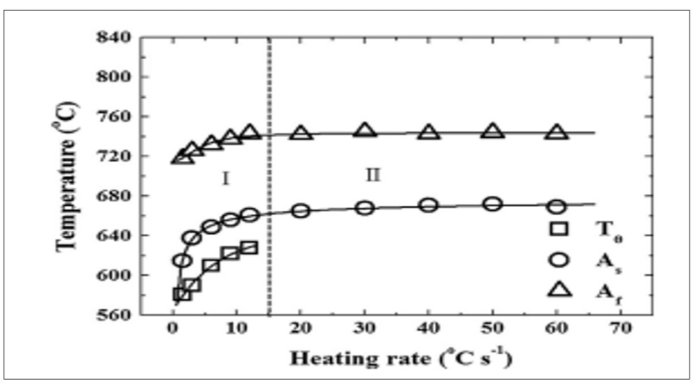

Figure 6. *Change in the critical temperatures of both cementite precipitation and the reverse transformation as a function of the heating rate for the 9Mn-based specimens [60]*

3.3. Annealing temperature effect

Depending on the annealing temperature three scenarios can be obtained as illustrated in the sketch shown in Fig. 7.

As the annealing temperature is lowered (Fig.7), the amount of retained austenite decreases. Consequently, after cooling from low temperatures, the level of retained austenite is very low, but its stability is quite high [61]. On the other hand, when the intercritical annealing temperature is high, the amount of retained austenite increases. However, a large portion of the reverted austenite transforms into new martensite during cooling due to its instability. This results in a lower overall amount of retained austenite. Therefore, the optimal amount of retained austenite is achieved at a middle range annealing temperature, where there's a good balance between the amount of retained austenite and its stability. This combination leads to the maximum amount of austenite remaining after cooling.

3.4. Annealing time effect

For medium manganese steels, the length of the annealing time primarily affects the balance between the amount of retained austenite, grain size, alloy composition, and the stability of the reverted austenite. This influence is similar to that of the annealing temperature. Based on research by W.Q. Cao et al [62] on Fe-0.2C-5Mn medium Mn steel, it was found that extending the annealing time at 650°C for up to 144 hours results in an increased volume fraction of austenite. Additionally, the austenite grains become thicker and enriched with manganese. The amount of retained austenite steadily grows in proportion to the logarithm of annealing time, but this increase eventually stabilizes after 12 hours of annealing.

Therefore, the improved mechanical properties (Fig. 8) especially the excellent combination of ultimate tensile strength (~960 MPa) and total elongation (~45%), were mainly due to the increased TRIP effect from the large fraction of austenite (34%) obtained after annealing for 6h at 650°C.

3.5. Cooling rate effect

The way in which a medium manganese steel is cooled after being heated and held at a constant temperature significantly affects its microstructure. A recent study by Furukawa et al [52] on various manganese steels found that steels with more than 0.1% carbon are highly sensitive to the cooling rates.

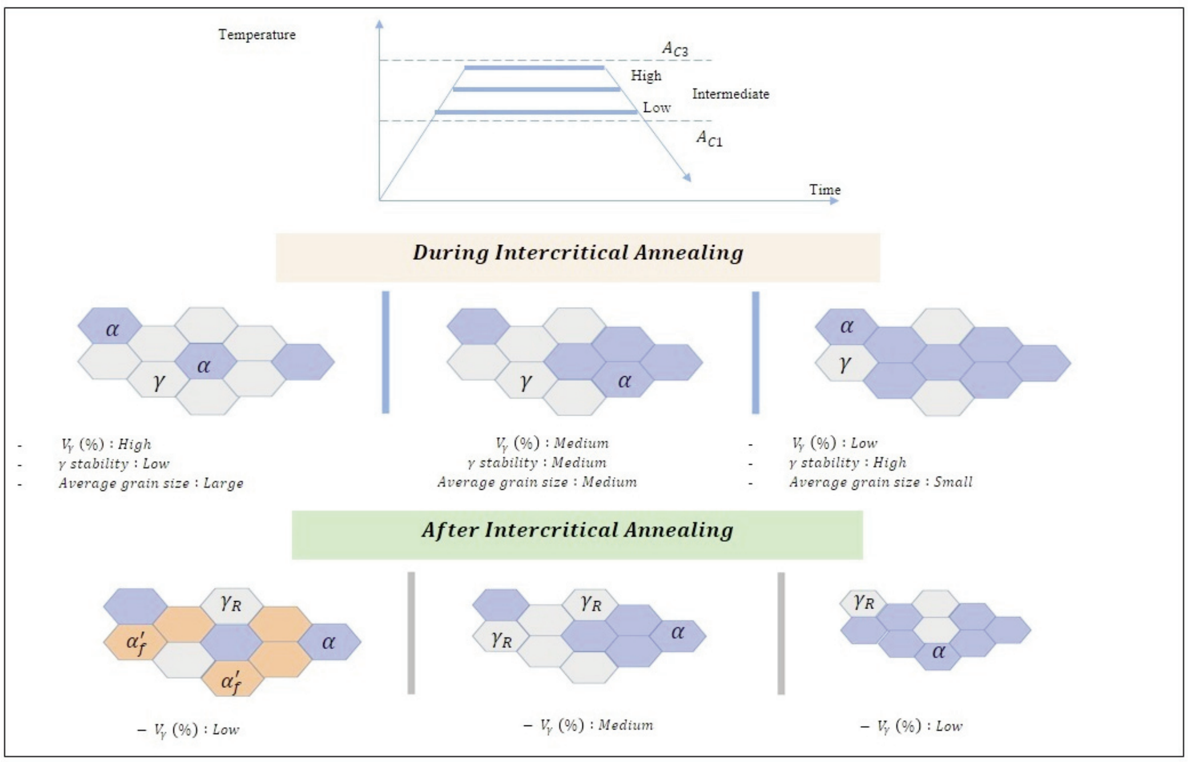

Figure 7. *Sketch of microstructure evolution as function of intercritical annealing temperature: α is ferrite, γ is reverted austenite, γ_R is retained austenite and α_f' is fresh martensite [61]*

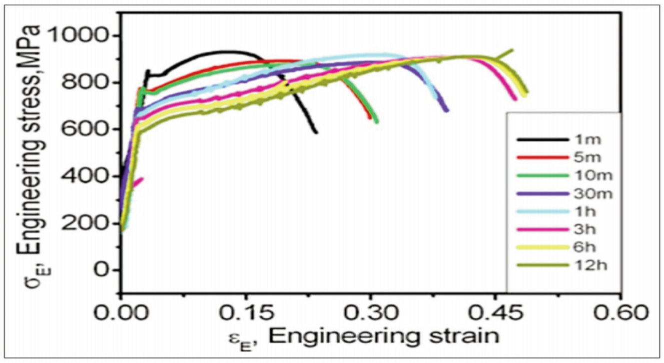

Figure 8. *Effect of intercritical annealing time on the mechanical properties [62]*

For instance, Fe-5Mn-0.3C steel cooled rapidly in water retained a high amount of austenite (44.1%) while preventing the formation of carbides. In contrast, slower cooling in a furnace led to a much lower amount of retained austenite (31.2%) due to the formation of a significant quantity of cementite.

On the other hand, the impact of rapid cooling on the microstructure and mechanical properties of low-carbon, high-strength steel, annealed in the intercritical region, was studied by L. Zhuang et al [53] using a Gleeble 1500 thermomechanical simulator and a continuous annealing thermomechanical simulator, their results revealed that the microstructure primarily consisted of ferrite and bainite, with minor quantities of retained austenite and martensite islands forming at cooling rates of 5°C/s and 50°C/s respectively.

The highest ultimate tensile strength (UTS) and yield strength (YS) of 1450 MPa and 951 MPa, respectively, were achieved for the sample cooled at a rate of 50°C/s. This is attributed to the dispersion strengthening effect of finer martensite islands (Fig.9), and the precipitation strengthening effect of carbide precipitates.

4. Mechanical properties of medium Mn steels

Several studies [42, 49, 63, 64, 65] have shown that medium manganese steels are prone to plastic instabilities. These instabilities can result in cracking during deep drawing or a rough surface that negatively impacts galvanizing. Common forms of plastic instability in these steels include Luders bands and the Portevin-Le Chatelier (PLC) effect. The occurrence of these instabilities is influenced by both internal and external factors. Internal factors include grain size, shape, dislocation density, and the concentration of elements like carbon and nitrogen [66]. External factors are strain rate and temperature. In the case of medium manganese steels, the transformation-induced plasticity (TRIP) and twinning-induced plasticity (TWIP) effects, as well as the stability of retained austenite, further contribute to the development of these plastic instabilities [65].

4.1. Luders bands in medium Mn steels

Luders bands are typically caused by static strain aging. They appear immediately after the initial plastic deformation, following the yield point drop, and

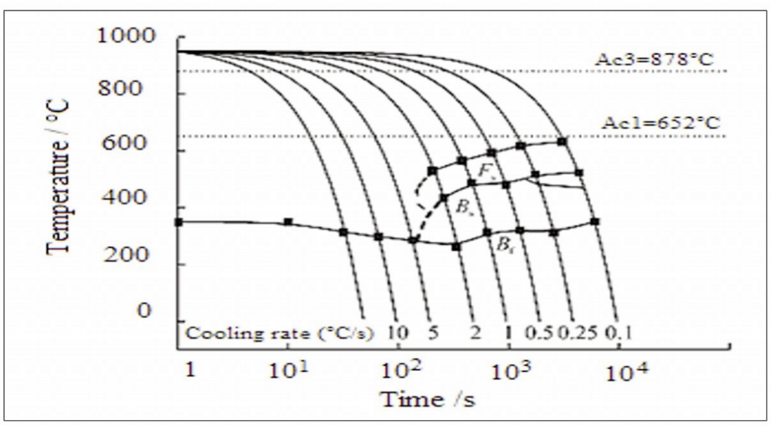

Figure 9. *Continuous cooling transformation curve of the investigated steel [53]*

continue through the plateau region of the stress-strain curve [65]. In medium manganese steels, this phenomenon is linked to manganese content. S. Lee et al [67] found that Luders strain increases as manganese concentration rises in intercritically annealed Fe-(5 ,7 ,9)Mn - 0.05C steels, as illustrated in Fig. 10.

Eliminating Luders bands in medium manganese steels through heat treatment is challenging without compromising the material's mechanical properties. Research by Such et al [10] on Fe-6Mn-0.12C-0.5Si-3.1Al steel revealed that lower annealing temperatures result in a longer stress plateau. Conversely, higher annealing temperatures led to a shorter stress plateau, as depicted in Fig. 11.

Conversely, regarding the deformation mechanisms at play, X.G. Wang et al [42] found through energy analysis of cold-rolled Fe-7Mn-0.14C-0.23Si medium manganese steel that strain-induced martensite formation primarily occurs within Luders bands, with minimal formation observed in Portevin-Le Chatelier (PLC) effect.

4.2. PLC effect in medium Mn steel

The PLC effect in polycrystals is typically categorized into three types (or a combination of them) based on the spatial arrangement of the local deformation bands and the specific shape of the stress-strain curve. As the strain rate increases from the lower limit of plastic instability, a progression of PLC effect types can be observed, reflecting an increasing correlation between the deformation bands: random nucleation bands (type C) transitioning to relay-racing-style bands (type B), and ultimately to the propagation zone (type A) [68]. Unlike Luders bands, the Portevin-Le Chatelier (PLC) bands are associated with dynamic strain aging (DSA). They manifest as distinctive saw-tooth patterns on the stress-strain curve. Various theories explain the serrated flow behavior in steels. The most widely accepted explanation involves the interaction between solute atoms (like carbon) and moving dislocations, a concept originally introduced and subsequently refined by Cottrell [49, 69, 70]. Unlike traditional steels, medium manganese steels exhibit complex behaviors like TRIP and TWIP and have multi-phase microstructures. This makes understanding the Portevin-Le Chatelier (PLC) mechanism in these steels particularly challenging. Consequently, there are limited studies exploring the nature of plastic instability in this type of steel. Yang et al [71] found that PLC bands in intercritically annealed 0.22C-7.2Mn-2.4Al medium manganese steel only form within austenite grains. This is attributed to the higher carbon content in the retained austenite compared to ferrite. Similarly, Sun et al [65] linked the occurrence of PLC serrations to strain-induced martensitic transformation in 0.2C-11.6Mn-2.7Al medium manganese steel.

PLC bands represent localized areas of strain where metastable austenite grains are prone to transforming into martensite due to intense stress, as reported in [71, 72]. Additionally, the influence of twinning-induced plasticity on PLC bands is similar to that observed in TWIP steels, primarily linked to the interaction of carbon-manganese pairs with dislocations during deformation, as described by A. Kozłowska et al [49]. Furthermore, the manufacturing process applied to these steels significantly impacts the occurrence of plastic instabilities. Hot-rolled medium manganese steels only exhibit Portevin-Le Chatelier (PLC) bands, with no evidence of discontinuous yielding. In contrast, both Luders bands and PLC effects can be observed in cold-rolled, then intercritically annealed medium manganese steels, as shown in Fig. 12.

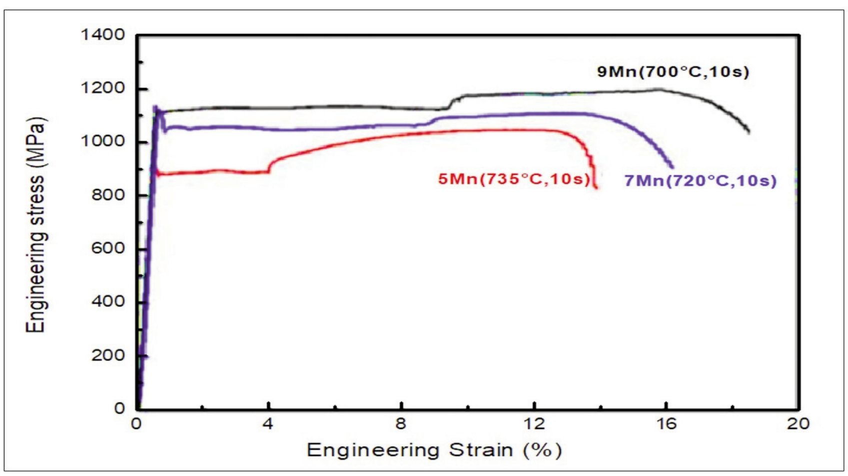

Figure 10. *Engineering stress–strain curves of Fe-(5, 7, 9)Mn–0,05C (wt.%) cold rolled steels annealed for 10s at 735, 720 and 700°C respectively [67]*

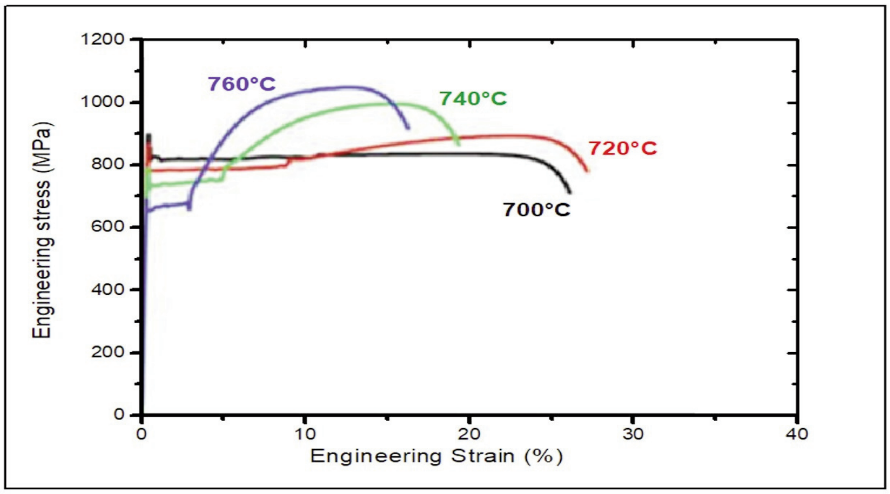

Figure 11. *Engineering stress–strain curves of Fe–6Mn–0,12C–0,5Si–3,1Al (wt-%) cold rolled steel annealed for 2 min tensile tests were performed at various intercritical annealing temperatures [10]*

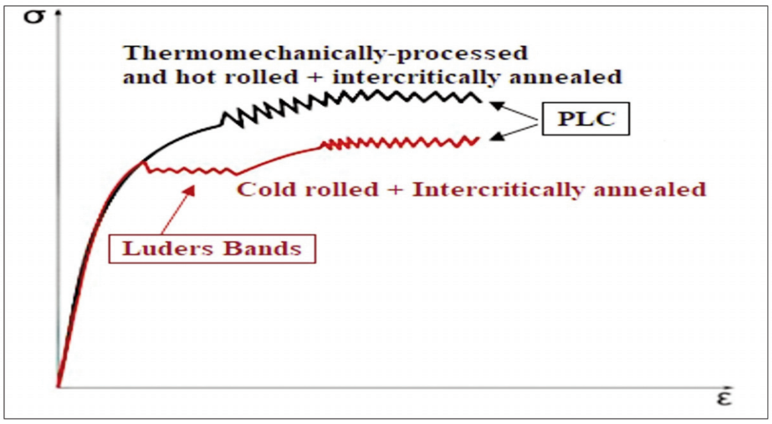

Figure 12. *Types of plastic instability in medium-manganese steels [49]*

Conversely, Y. Wang et al [73] investigated the relationship between cementite formation and the Portevin-Le Chatelier (PLC) effect in a hot-rolled medium manganese steel. They concluded that the formation of carbides significantly reduces the PLC effect by lowering the concentration of interstitial atoms in the steel's structure.

5. Conclusions

This review examines how the microstructure of medium manganese steels changes based on the initial chemical composition and different processing methods, including hot and cold rolling, as well as under heat treatment conditions like heating rate, cooling rate, annealing temperature, and holding time. Therefore, the following main conclusions can be drawn from the analysis of some previous works :

Austenite stability in medium Mn steels depends on multiple conditions: chemical composition, deformation mode, annealing temperature, and processing conditions.

To fully benefit from the advantages of medium manganese steels, it is essential to understand the effects of each processing condition on austenite stability;

Austenite stability is a crucial factor in determining the mechanical properties of medium manganese steel mainly consisting of ferrite and austenite. During the deformation process, the phase composition undergoes dynamic changes, and the nucleation and expansion of the PLC band are closely linked to the distribution of phases in medium manganese steel.

Abbreviation list

AHSS : Advanced High Strength Steels;

3GAHSS : Third Generation of Advanced High Strength Steels;

BIW : Body In White;
CP : Complex Phase;
DP : Dual Phase;
DSA : Dynamic Strain Aging;
FMDP: Ferrite Martensite Duplex Phase;
FADP : Ferrite Austenite Duplex Phase;
IA : Intercritical Annealing;
L-IP : Lightweight -Induced Plasticity;
MM : Medium Mn;
PLC : Portevin-Le Chatelier;
PSE : Product of Strength and Elongation;
RA: Retained Austenite:
S-IP : Shear-Induced Plasticity;
TE : Total elongation;
TRIP : Transformation Induced Plasticity;
TWIP : Twinning Induced Plasticity;
UFG : Ultra Fine Grained;
UTS : Ultimate Tensile Strength;

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author contribution statement

Hamza ESSOUSSI : Conceptualisation, writing the original draft ; Elhachmi ESSADIQI : Review & editing ; Said ETTAQI : Review & editing

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OD DIZAJNA LEGURE DO MIKROSTRUKTURNIH I MEHANIČKIH SVOJSTAVA SREDNJE MANGANSKIH ČELIKA TREĆE GENERACIJE NAPREDNIH ČELIKA VISOKE ČVRSTOĆE

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Apstrakt

Automobilska industrija suočava se sa sve većim pritiscima da smanji težinu vozila, unapredi bezbednost i smanji troškove proizvodnje, istovremeno ispunjavajući strože ekološke propise. Različita rešenja su razvijena kako bi se efikasno odgovorilo na ove često suprotstavljene zahteve. Jedno od obećavajućih rešenja je razvoj novih vrsta čelika treće generacije naprednih čelika visoke čvrstoće (3GAHSS). Ovi čelici imaju za cilj da premoste jaz između TWIP i TRIP čelika. Takozvani srednje manganovi (MM) čelici kombinuju izuzetnu čvrstoću, dobru plastičnost i niže troškove proizvodnje zahvaljujući smanjenoj upotrebi legirajućih elemenata poput mangana (manje od 12 tež. %). Srednje manganski čelici privlače sve veću pažnju kao materijali za projektovanje budućih karoserija i struktura vozila. Stoga, ovaj rad ima za cilj da istraži odnos između hemijskog sastava, mikrostrukture, procesa proizvodnje i mehaničkih svojstava srednje manganskih čelika.

Ključne reči: *Srednje manganski čelici; Interkritično žarenje; Zaostali austenit; Mikrostruktura; Termo-mehanička obrada*