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# Effect of Ferrite-Martensite Microstructural Evolution on Hardness and Impact Toughness Behaviour of High Martensite Dual Phase Steel

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**Abstract:** In an attempt to improve strength and impact toughness resistance, high martensite dual phase steel (HMDP) was developed in low carbon microalloyed steel using an intermediate annealing heat treatment at different temperatures and period of annealing. In this condition, both coarse and fine-ferrite and martensite (dual phase) microstructures were produced with a variable volume% of martensite ($V_m$), which ranged from 35 to 71%. Hardness and impact toughness tests were conducted on HMDP steel specimens, which had different martensite volume fractions and heat-treatment conditions. Optical microscopy was employed to examine the microstructural basis for the mechanical properties. It has been observed from the investigation that both hardness and impact toughness values significantly increased with increasing martensite volume fraction for $V_m$ between 35-64% and then decreases. It was also seen that HMDP steel specimens with martensite content varied from 52-64% exhibited excellent combination of mechanical properties for both hardness and toughness with the optimum obtained at $V_m$ = 64%. This is attributed to the finer ferrite-martensitic microstructure and carbide precipitate-free ferrites in the HMDP steel specimens intercritically annealed at high temperature. An increase in the intercritical treatment time from 30minutes to 90 minutes leads to increase in the martensite volume fraction as well as both charpy and Vickers hardness values for the developed HMDP steels.

**Keyword:** High Martensite, Dual-Phase Steel, Annealing, Ferrite-Martensite, Microstructure, Hardness,; Impact Toughness

## INTRODUCTION

After years of losing ground in automotive applications to Aluminium, steel is winning interest back with lighter and higher-strength steel grades (k. Halka, 2000). Evaluation of newer materials with improved combinations of strength, ductility and toughness has led to the development of a series of microstructure-strengthened steels, in which dual phase (DP) steels represent a distinguished class (S.B. Prichard and A.J. Trowsdale, 2002).

DP steels are one of the important new advanced high strength (AHSS) product developed for the automobile industry (Giorgio, P. and C.C. Maria, 2004). They offer, besides higher strength, possibilities to reduce weight and increase passenger safety (Huang J., *et al.,* 2004). DP microstructure consists typically of a dispersion of a hard phase islands in a ductile matrix of ferrite. The second phase is usually martensite, but other low-temperature constituents, such as bainite, can be present (Waterscoot, T., L. Kestens, and B.C. De Comann 2002; Saikly, T., *et al.,* 2001).

The amount of martensite present in ferrite-martensite steel will depend on the intercritical annealing temperature in the ferrite plus austenite region. Further increasing the volume fraction of martensite increases the strength of the dual phase material. Unfortunately, increasing the martensite content might reduce ductility and toughness (Hulka, K., 2000.; Prichard, S.B., A.J. Trowsidale, 2002.; Saikly, T., *et al.,* 2001.; Pichler, A., *et al.,* 2000).

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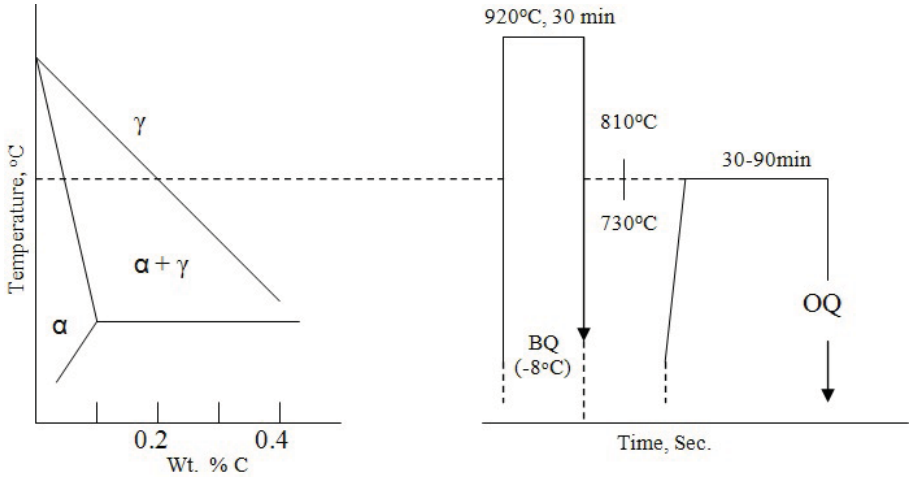


**Fig. 1:** Schematic representations of intermediate quench heat-treatment schedules.

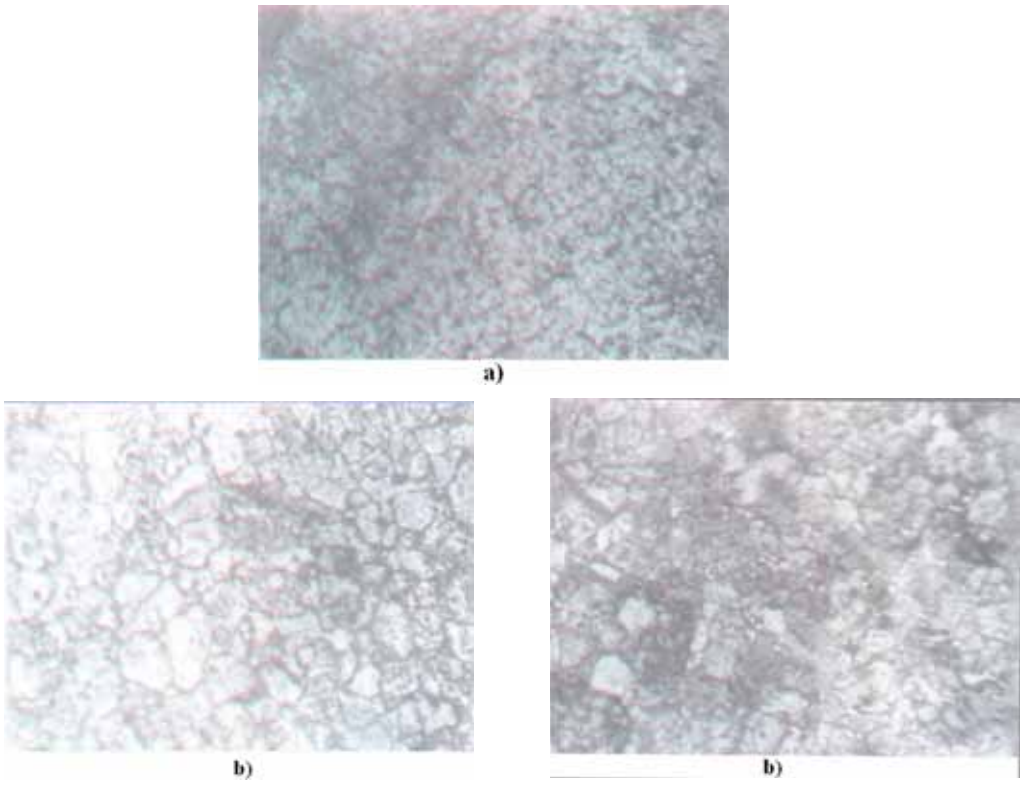


**Fig. 2:** Photomicrographs (100x) of IQ-treated HMDP steels intercritically annealed at 730°C for (a) 30min (b) 60min (c) 90min .2%Nital etch.

However, to maintain high ductility and toughness in these steels, the previous study by Hulka (Hulka, K., 2000) has indicated that it is desirable to control either martensite content or the steel chemistry. Based on the microstructure alone, Bag *et al.,* (2004) have suggested that high martensite dual-phase (HMDP) steels with an excellent combination of strength, ductility and impact toughness can be prepared by intermediate quench heat treatment. The treatment will result in finer distribution of ferrite and martensite microstructure (Hulka, K., 2000).

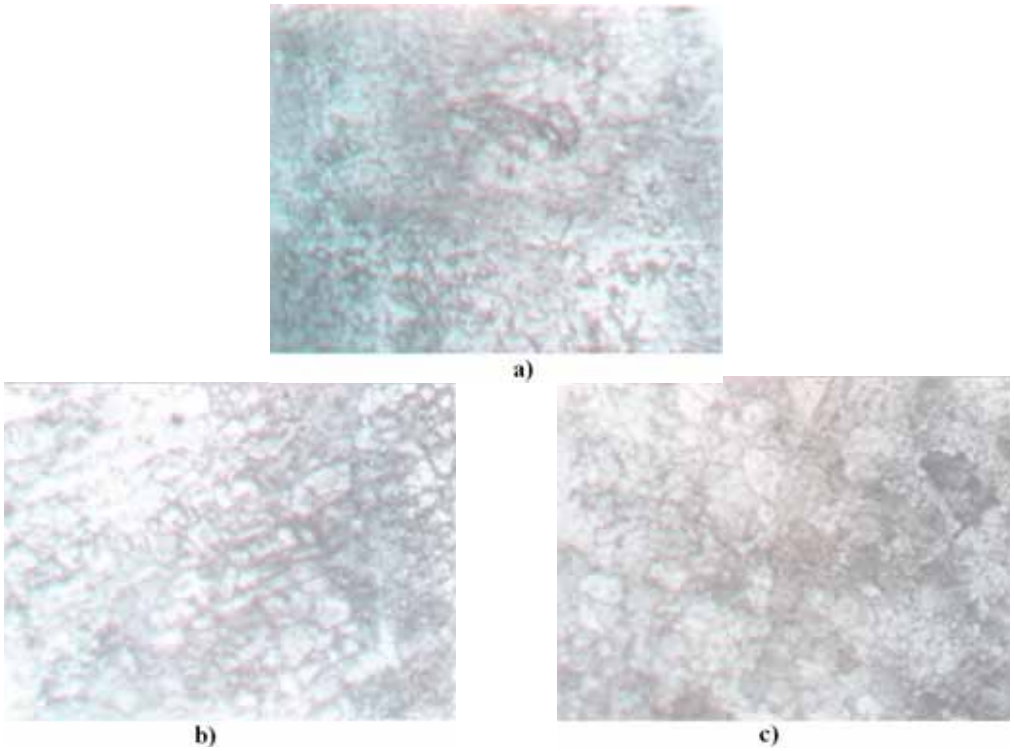


**Fig 3:** Photomicrographs (100x) of IQ-treated HMDP steels intercritically annealed at 750°C for (a) 30min (b) 60min (c) 90min .2%Nital etch.

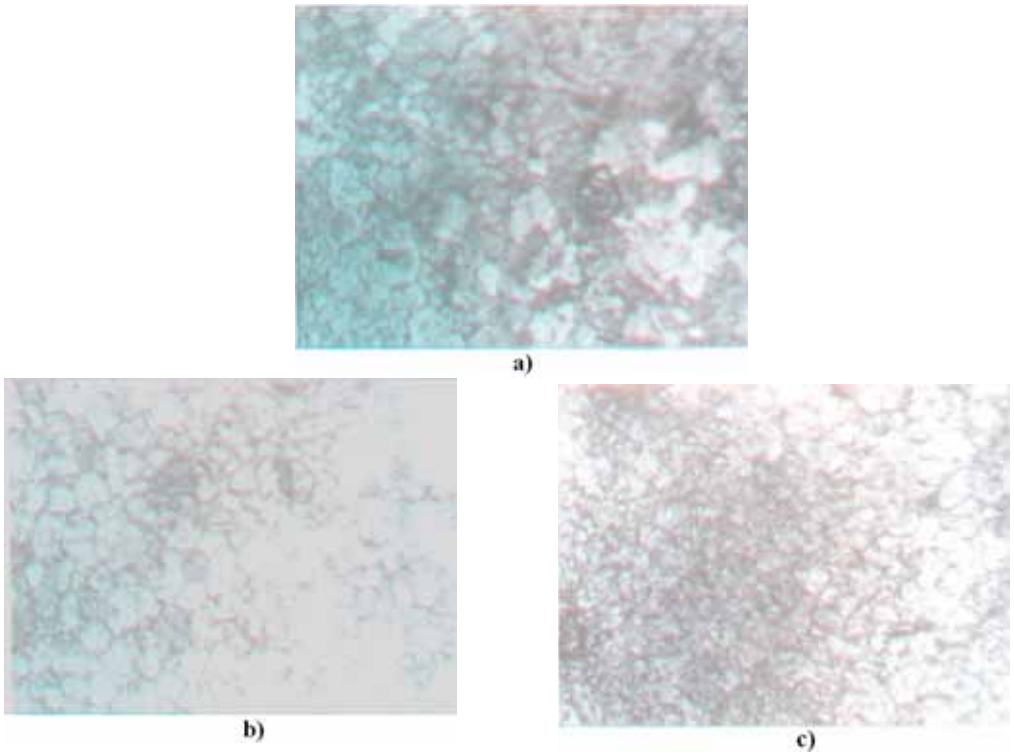


**Fig. 4:** Photomicrographs (100x) of IQ-treated HMDP steels intercritically annealed at 770°C for (a) 30min (b) 60min (c) 90min .2%Nital etch.

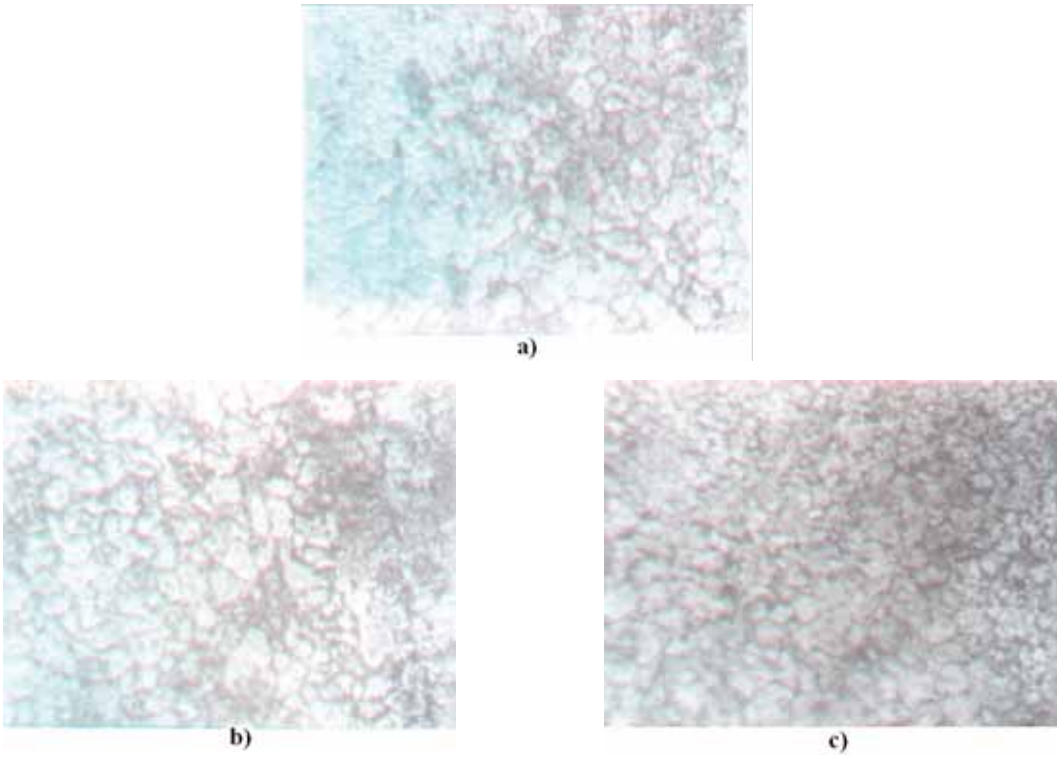


**Fig 5:** Photomicrographs (100x) of IQ-treated HMDP steels intercritically annealed at 790°C for (a) 30min (b) 60min (c) 90min .2%Nital etch.

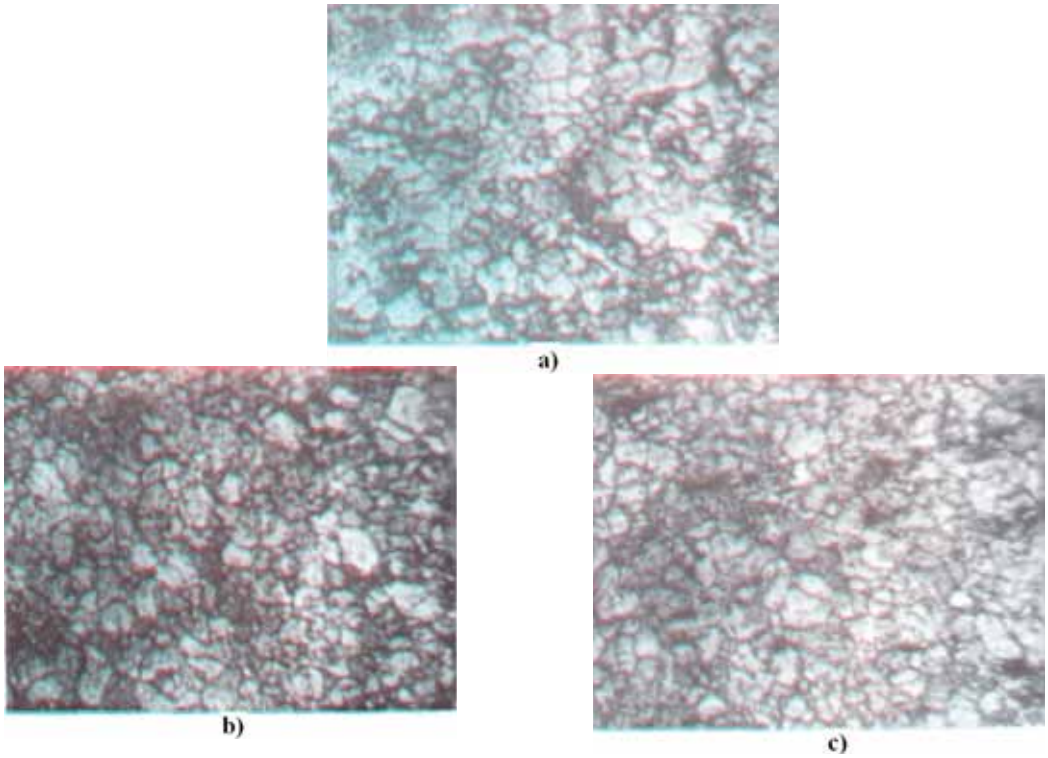


**Fig. 6:** Photomicrographs (100x) of IQ-treated HMDP steels intercritically annealed at 810°C for (a) 30min (b) 60min (c) 90min .2%Nital etch.

The present studies concern the alteration of ferrite-martensite microstructural evolution by changing the volume fraction of martensite brought about by varying intercritical temperature and period of annealing using the hardness and toughness properties as criteria.

## MATERIALS AND METHODS

Commercial microalloyed steel used in the present investigation was analysed using a Metal Analyser Spectrometer (Model Fission 3460). Table1 lists the chemical composition. The samples were supplied in hot rolled condition.

To obtain ferrite-martensitic microstructures with varying martensite content, samples forexperimental were subjected to intermediate quench heat treatment schedule as shown in figure1. In this technique, the specimens were first austenitized at 920°C followed by rapid cooling/quenching in iced brine (BQ) to produce 100% martensite. These specimens were subsequently held at different intercritical temperature (730°C, 750 °C, 770 °C, 790 °C, 810 °C) for the periods of 30minutes, 60minutes, and 90minutes respectively and were finally quenched in oil (OQ).

Samples for metallographic examinations were ground on water lubricated hand-grinding set- up of abrasive and polishing was carried out on a 6-inch rotating disc of a METASERV Universal Polishers machine. These were then analyzed using a Wild M50 metallurgical microscope after etching in 2% Nital. The volume fractions of ferrite and martensite were determined using a Mean Linear Intercept (MLI) method. Vickers hardness tests were performed with a load of 30kgf and minimum of ten points were measured for each heat-treated sample. Impact tests were carried out at room temperature (30°C) using a standard pendulum-type Charpy impact-testing machine.

## RESULTS AND DISCUSSIONS

***Evolution of Microstructure:***

Typical intermediate quench-treated DP steel samples for different volume percentage of martensite are shown in fig.2-6.The microstructure is characterized by the distribution of martensite (black) in ferrite matrix (white). The volume fraction of martensite ($V_m$) was found to vary from 35%-71% consequent upon changing the intercritical annealing temperature. As it can be seen, micrographs of the specimens with Volume % of martensite varied from 35%-43% consisted fine particle of undissolved carbides (Figures 2 and 3). Bag *et al.,*(2004). reported these precipitates formed during the reheating process to intercritical temperature and the amount of the carbides decreases as the volume percentage of martensite increases. Also, optical micrographs in figures 2 and 4 reveal that the microstructure of the HMDP steels consist of fine ferrite and martensite phases ($V_{m=}$ 52-64%). Coarse martensite was obtained with further increase in $V_m$ beyond 64% up to 72% in the HMDP steel specimens investigated. Generally, the volume fraction of martensite increased with the increasing period of annealing for each intercritical temperature through 30minutes, 60minutes and 90minutes. This is in agreement with the previous report (Cota, A.B., *et al.,* 2003).

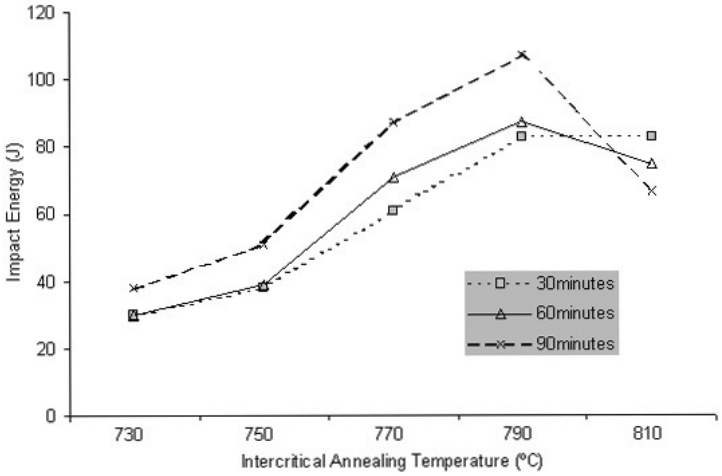


**Fig. 7:** Charpy Impact energy of IQ-treated HMDP steels as a function of intercritical treatment temperatures and times

**Table 1:** Chemical Composition

Units Wt. Pct (%)

| C | P | S | Mn | Si | Mo | V | Ti |
|---|---|---|---|---|---|---|---|
| 0.22 | 0.025 | 0.025 | 1.20 | 0.25 | 0.001 | 0.004 | 0.002 |

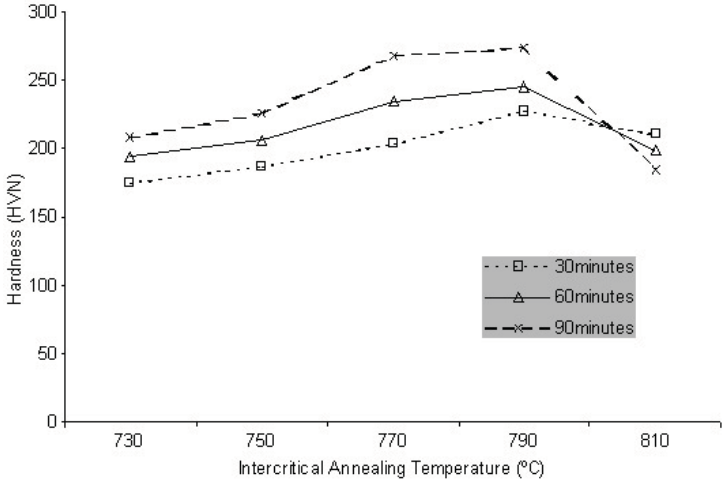


**Fig. 8:** Vickers hardness of IQ-treated HMDP steels as a function of intercritical treatment temperatures and times

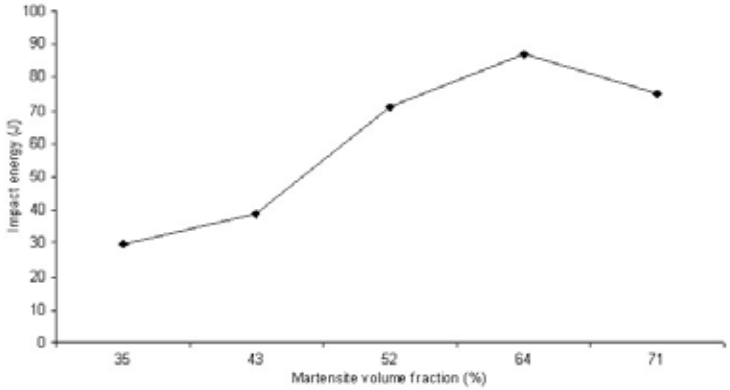


**Fig. 9:** Evolution of charpy impact energy of IQ-treated HMDP steels with the martensite volume fraction.

***Influence of Microstructure on Hardness:***

Figure 7 and 8 reveal the evolution of the Vickers hardness (HVN) with intercritical treatment temperatures and with martensite volume fraction respectively. As shown, it can be observed that hardness values increases with increasing $V_m$ in the range between 35% to64%. A further increase in the $V_m$ was to decrease the hardness. Clearly this result indicates that the DP steel with fine distribution of ferrite and martensite (52%-64%) will have high hardness value. The low hardness obtained at the lower intercritical ($V_m$ =35%) is reported to be attributed to the presence of carbide precipitates and coarser ferrite Bag A., *et al.,* 2004, whereas, low hardness at higher intercritical temperature ($V_m$ >64%) is due to coarser martensite. As revealed in Fig.7, an increase in the intercritical annealing treatment time leads to increase in the steel hardness.

***Microstructure and Impact Toughness:***

The influences of volume fraction of martensite as a function of intercritical treatment temperature on the impact toughness of the developed HMDP steel are given in the figures 9 and 10. As expected, the impact toughness usually decrease as the volume % of martensite ($V_m$) increases (Sudhakar, K.V., and E.S. Dwarakadasa, 2000). However, as can be seen from the figures opposite tendency was obtained i.e as the volume % of martensite is raised, the impact toughness increases, peaks at $V_m$=64% and then decreases.

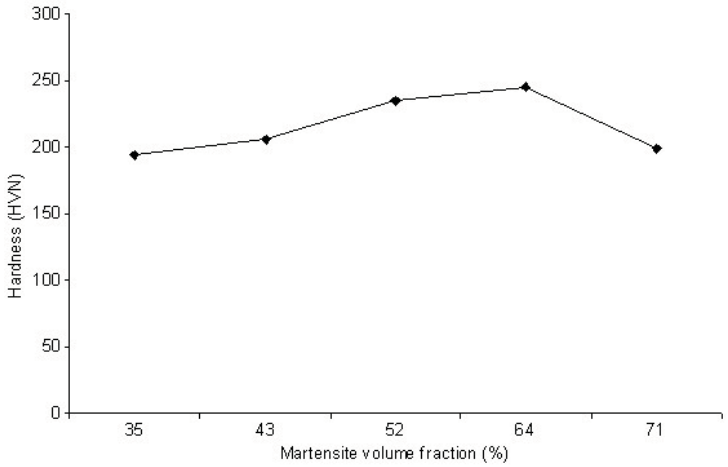


**Fig. 10:** Evolution of impact energy of IQ-treated HMDP steels with the martensite volume fraction.

This follows the same trend obtained for hardness properties of these steel specimens. The initial increase is due to tougher martensite formed at higher temperatures resulting from finer micro constituents in the steel (Sudhakar, K.V., and E.S. Dwarakadasa, 2000). The decrease in the impact toughness has been attributed to the coarser ferrite and martensite obtained in the specimen with lower ($V_m$<43%)and higher ($V_m$>64%) martensite content respectively. Hence it can be concluded from the present investigation that higher toughness as well as hardness values are significantly associated with the finer distribution of martensite and ferrite composite microstructure.

***Conclusions:***

The current work has focussed on the impact of microstructural evolution on the hardness and impact toughness of high martensite dual phase steel developed by intermediate quench heat treatment technique. The following conclusions have been drawn:

- The intermediate quench heat treatment procedure was so effective in improving the mechanical properties including hardness and impact toughness of the developed HMDP steels.
- The hardness and impact toughness values of HMDP steel specimen with finely distributed constituent ($V_m$=52%-64%) are superior to those of coarse microstructure ($V_m$<43% and $V_m$>64%).
- On intercritically annealed for different lengths of time, the steel showed increased in the martensite volume fraction in different proportion that significantly affect the hardness and impact toughness of the steel.
- The impact toughness behaviour of the steel showed an unusual nature as it increases as the martensite content is raised.
- The best combination of Vickers hardness and Charpy Values were observed for DP steel samples containing martensite content in the range $V_m$=52%-64%. This is attributed to the finer microstructural constituents and carbide-free ferrite obtained in this region.

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