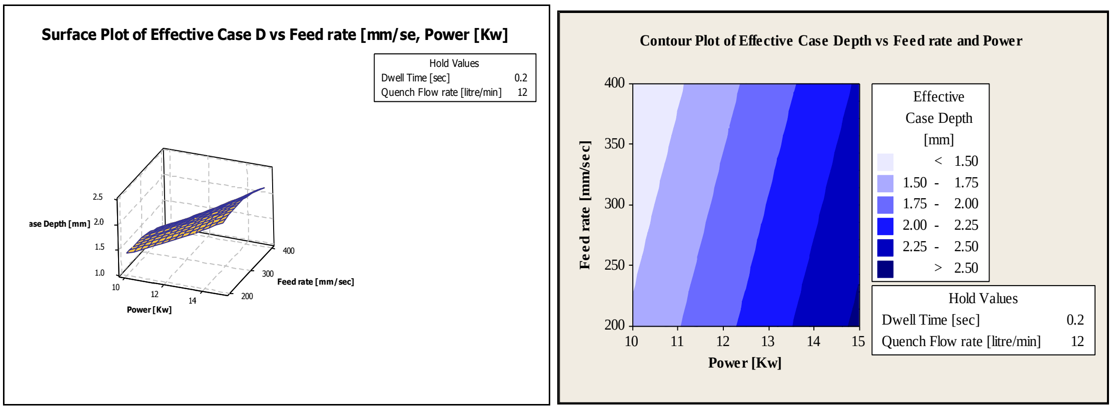

Figure 3. a) Surface and Contour Plot for Case Depth vs feed rate, power

In contour plot graph, power (Kw) is plotted on x axis and feed rate (mm/sec) on y axis and dark blue colour shows max case depth. As power increases case depth also increases, maximum case depth gets in the range of 14-15 Kw whereas feed rate increases case depth decreases, maximum case depth gets in the range of 200-250 (mm/sec) keeping other parameters constant.

Figure 3b shows the effect of dwell time and feed rate on case depth. As dwell time increases, case depth increases, also as feed rate increases case depth decreases, keeping other parameters constant i.e. power 12.5Kw, quench flow rate 12 lit/min.

In contour plot graph, feed rate (mm/sec) is plotted on x axis and dwell time (sec) plotted on y axis. As feed rate increases case depth decreases, maximum case depth gets in the range of 200 mm/sec whereas dwell time increases case depth increases, maximum case depth gets in the range of 0.30 sec keeping other parameters constant.

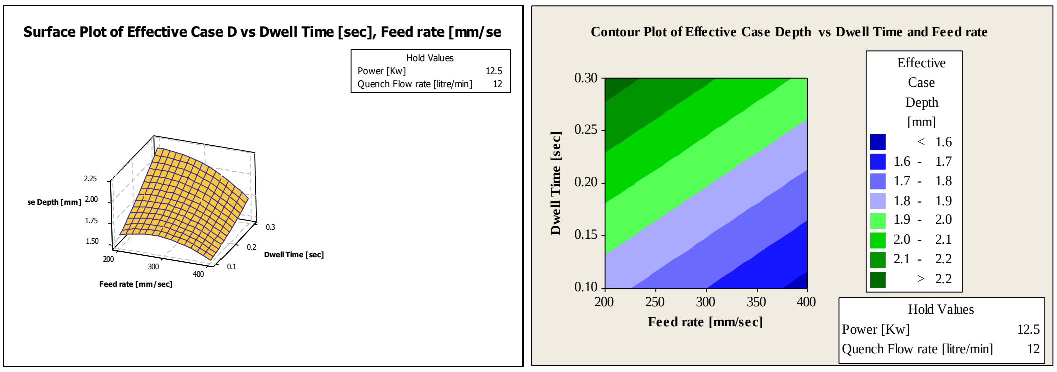

Figure 3. b) Surface and contour plot for case depth vs dwell time, feed rate

Figure 3c shows the effect of quench flow rate and dwell time on case depth. As dwell time increases case depth increases, quench flow rate increases case depth decreases keeping other parameters constant power 12.5Kw, feed rate 300 mm/sec.

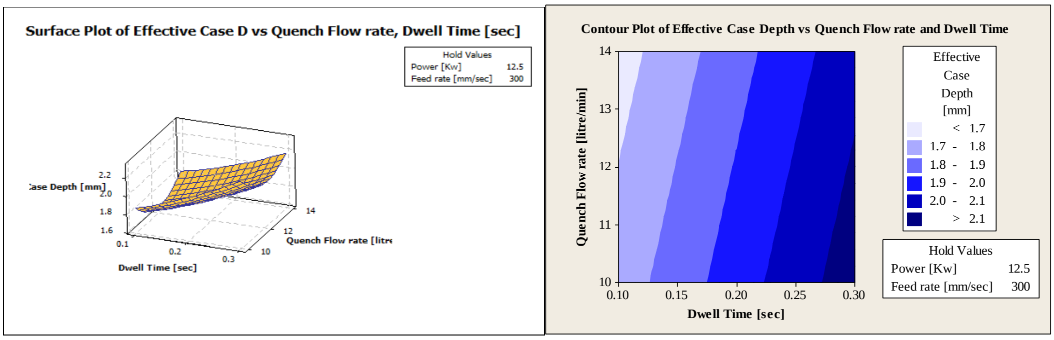

Figure 3. c) Surface & contour plot for case depth vs dwell time, and quench flow rate

In contour plot graph, dwell time (sec) is plotted on x axis and quench flow rate (lit/min) plotted on y axis and dark blue colour shows max case depth. As dwell time increases case depth increases, maximum case depth gets in the range of 0.25-0.3 sec whereas quench flow rate increases case depth decreases maximum case depth gets in the range of 10-11 lit/min keeping other parameters constant.

Multiple Response Optimizations

MINITAB software was used for maximizing (achieving target values) hardness and ECD. The optimum values of process parameters obtained were power 15 Kw, feed rate 200 mm/sec, dwell time 0.30 sec and quench flow rate 14 lit/min, the maximum case hardness and ECD obtained 59.83 HRC and 2.70 MM. All the values were within 95% prediction interval.

Table 5. Multiple response optimizations

Response	Goal	Lower	Target
Case hardness [HRC]	Maximum	48	60
E Case depth [MM]	Maximum	1.4	2.8

Table 6. Experimental validation

Trial No.	Optimum conditions	Case hardness		% error	Effective Case depth		% error
		Experimental	Predicted	Case Hardness	Experimental	Predicted	Case depth
01	P= 15kw; F = 200 mm/sec; D= 0.3 sec; Q=14 litre/min	58.0	59.83	3.05	2.58	2.7	4.44
02		59.0	59.83	1.38	2.6	2.7	3.7

MICROSTRUCTURE ANALYSIS

The goal of heat treatment of steel is very often to attain a satisfactory hardness. The important micro-structural phase is then normally martensite, which is the hardest constituent in low-alloy steels. The hardness of martensite is primarily dependent on its carbon content. If the micro-structure is not fully martensitic, its hardness is lower. In practical heat treatment, it is important to achieve full hardness to a certain minimum depth after cooling, that is, to obtain a fully martensitic microstructure to a certain minimum depth, which also represents a critical cooling rate.

A finely distributed structure like tempered martensite is more rapidly transformed to austenite than, for instance, a ferritic-pearlitic structure. This is particularly true for alloyed steels with carbide-forming alloying elements such as chromium and molybdenum

In case of induction hardening process uniform distribution of carbon cannot be assumed, the time spent at the austenitizing temperature can be so brief that carbon cannot diffuse to a uniform concentration throughout the microstructure. Determination of 100% martensite is subjective and difficult to determine optically (Tartaglia Eldis 1984). The figure shows microstructure image light microscope photograph at 20X of the surface of sample piece of low hardness at 48 HRc and of optimum hardness at 60 HRc of induction hardened 41Cr4 steel, polished and etched at 3% Nital solution. No micro cracks observed in the induction hardened zone.

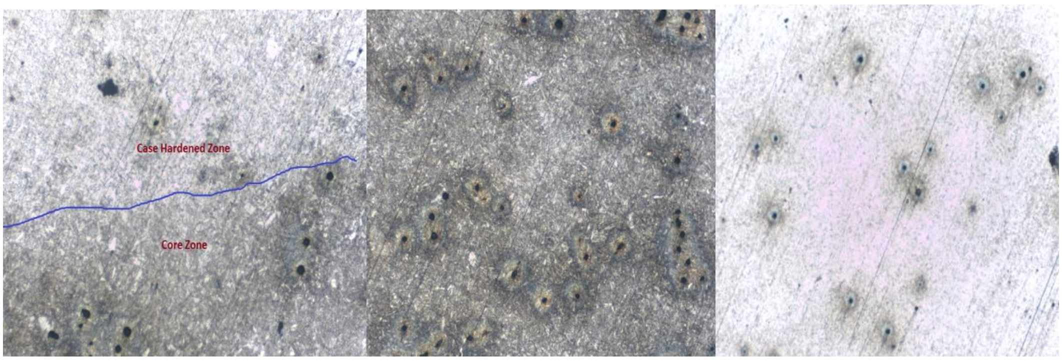

Figure 4. Microstructure of sample piece low hardness at 48 HRc a) Micrograph at interface hardened and unhardened zone b) Micrograph at unhardened zone c) Micrograph at hardened zone

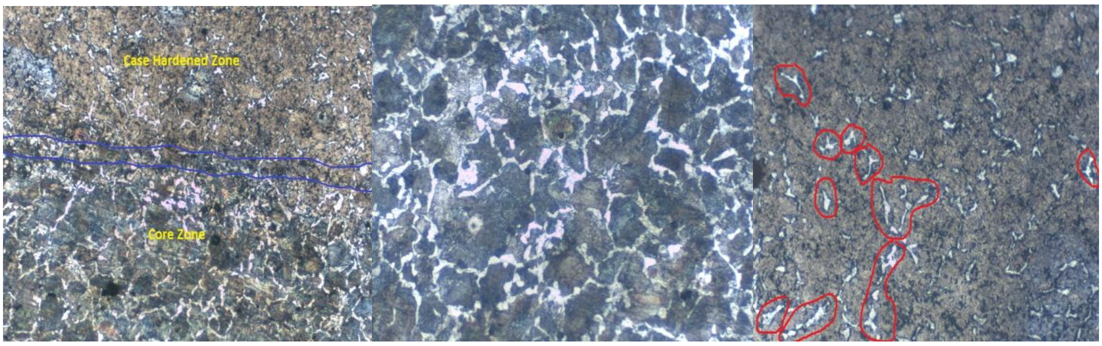

Figure 5. Microstructure of sample piece optimum hardness at 60 HRc a) Micrograph at interface hardened and unhardened zone b) Micrograph at unhardened zone c) Micrograph at hardened zone

CONCLUSIONS

From this experimentation study it has been concluded that

1. The most influencing parameters for the case hardness (CH) are the power; quench flow rate and Dwell time, in descending order.
2. The most influencing parameters for the Effective case depth (ECD) are the power; Dwell time and feed rate, in descending order.
3. The common optimum values of the process parameters for both responses case hardness (CH) and Effective case depth (ECD) are: Power = 15kw; Feed rate = 200 mm/sec; Dwell time = 0.3 sec; Quench flow rate = 14 litre/min. As the error between the experimental and predicted values is less than 5%, validates the experiment.
4. In the hardened region, complete martensitic phase was observed which confirms the hardening of the material

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