CHAPTER VII

RESULTS AND DISCUSSION
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VII.1 INTRODUCTION

All the results and conclusions were drawn by performing each experiment three times. Wherever necessary, the same experiments were again performed and mean values were recorded in the observation table and graphs were plotted.

In the first part of this chapter, results of electrochemical corrosion behavior of as-received, Cr-deposited, as-received laser irradiated, Cr-deposited laser irradiated, ion implanted and ion beam mixed maraging steel specimens have been discussed and conclusions are expressed. In the later part of the chapter, results of antimicrobial activity of above maraging steel samples for identified bacteria’s have been discussed and conclusions are expressed.

VII.2 CORROSION BEHAVIOR OF MARAGING STEEL

VII.2.1 CHROMIUM DEPOSITION

Electro-chemical corrosion behavior of maraging steel after chromium deposition using potentio-kinetic polarization technique:

The following different groups of maraging steel samples were studied for comparative study of electro chemical corrosion behavior [Shinde (1) et al., 2013].

a. As-received specimens.

b. As received specimen + chromium deposition (Cr-deposited specimens)

Typical potentio-kinetic polarization behavior of above mentioned specimens is shown in FIG.VII.1 (a) AND FIG.VII.1 (b). The mean values of the passive potentials and the critical current densities at the critical point G for various processed surfaces were recorded as shown in TABLE.VII.1.
FIG. VII.1 (a) shows electrochemical corrosion behavior of as-received maraging steel samples. The electrode potential at which an active transition to passive transition took place was found to be very important. This potential gives the characteristic property of the material under investigation. This electrode potential was observed to be -545 mV. The characteristic critical current density at point G was +99 µA / cm$^2$. In this case there was no stable passive region observed but the critical current density decreases as compared with as-received specimens.

In order to investigate, whether alloying element have beneficial effect related with current-voltage characteristics of the maraging steel, chromium with thickness ~250 Å was deposited on as received maraging steel samples. When Cr-deposited samples were subjected to their electro-chemical corrosion, behavior as shown in FIG.VII.1 (b) was observed.

There was no stable passive region occurred and the dissolution mechanism was similar to that of as-received specimens. The film formed during the process was found to be dissolving very slowly.

The critical current density obtained in this case was 74 µA / cm$^2$. The active to passive transition took place at -470mV electrode potentials. The corrosion behavior similar to that of pure chromium was observed.

FIG.VII.2 shows SEM Photograph of as-received maraging steel sample. FIG.VII.3 shows SEM Photograph of as-received maraging steel sample after corrosion treatment and FIG. VII.4 shows SEM Photograph of Cr-deposited maraging steel sample after electrochemical corrosion behavior. The surface morphology of the Cr-deposited samples clearly showed smoothness and few pits as compared to the as-received maraging steel samples as shown in FIG.VII.3. This result seems to be due to clinging of Cr ions. Most of the chromium ions remained clung to the surface. The surface morphology and electrochemical corrosion behavior showed that the chromium deposition preserves the surface of as-received maraging steel samples by increasing the corrosion resistance.

**CONCLUSIONS**

The electrochemical corrosion behavior of as-received and Cr-deposited samples was studied using potentio-kinetic polarization technique.
TABLE VII.1: - Average Critical current density and Average passive potential for various processed surfaces - CHROMIUM DEPOSITION

<table>
<thead>
<tr>
<th>Parameters</th>
<th>As-received</th>
<th>Cr-deposited</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical current Density</td>
<td>99</td>
<td>74</td>
</tr>
<tr>
<td>$\mu A/cm^2$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary passive Potential</td>
<td>-545</td>
<td>-470</td>
</tr>
<tr>
<td>(mV)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
FIG. VII.1 (a) CORROSION BEHAVIOR OF AS-RECEIVED AND
FIG. VII.1 (b) Cr-DEPOSITED MARAGING STEEL
FIG. VII.2: SEM PHOTOGRAPH OF AS-RECEIVED MARAGING STEEL BEFORE CORROSION TREATMENT

FIG. VII.3: SEM PHOTOGRAPH OF AS-RECEIVED MARAGING STEEL AFTER CORROSION TREATMENT
FIG. VII.4: SEM PHOTOGRAPH OF Cr-DEPOSITED MARAGING STEEL
(A) BEFORE AND (B) AFTER CORROSION TREATMENT
The corrosion behavior similar to that of pure Cr was observed. It was also observed that no stable passive region occurred and dissolution mechanism was similar to that of as-received specimens. It was concluded that the deposition of chromium material on the surface of maraging steel specimen increases corrosion resistance. The embrittlement of maraging steel can be avoided by depositing chromium.

**VII.2.2 LASER IRRADIATION**

Effect of LASER irradiation on corrosion behavior of as received and Cr-deposited Maraging Steel:

The following different groups of maraging steel samples were studied for their electrochemical corrosion behavior [Shinde (2) et al., 2013].

a. As-received specimens.
b. Cr-deposited specimens.
c. As-received specimen + laser irradiation (as-received laser irradiated specimens).
d. Cr-deposited specimen + laser irradiation (Cr-deposited laser irradiated specimens)

The SEM microphotographs from JEOL JSM 6360A machine facility was made available by Physics Department, Pune Department, Pune University Pune.

Typical potentiokinetic polarization behavior of above mentioned specimens is shown in FIG.VII.1 (a), 1 (b), FIG.VII.5 and FIG.VII.6. The potentials and current densities at critical point were noted. The mean of all values of passive potentials were noted along with mean currents for different specimens. These observations noted are shown in TABLE.VII.2.

Fig.VII.1 (a) shows the electrochemical corrosion behavior of as-received maraging steel sample. Active to passive transition was observed at -545mV electrodes potential. The characteristic critical current density at this point (point G) was +99 $\mu$A /cm$^2$. There was no stable passive region observed in this case.

Our intensions of the research problem selection or the aim was to control or minimize or reduce up to large extent or completely avoid corrosion of the alloy selected viz. maraging steel 250 grade. The review of the previous research work done was showed that the various metals alloyed with base metal can improve the corrosion characteristics.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specimen</th>
<th>Laser Irradiation on As-received specimen</th>
<th>Laser Irradiation on Cr-deposited specimen</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>As-received</td>
<td>0.6 J/cm$^2$</td>
<td>1.0 j/cm$^2$</td>
</tr>
<tr>
<td>Critical Current Density</td>
<td>Cr-deposited</td>
<td>+99</td>
<td>+74</td>
</tr>
<tr>
<td>(µA/cm$^2$)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
FIG.VII.5 CORROSION BEHAVIOR OF AS-RECEIVED LASER TREATED SPECIMENS
(a) 0.6j/cm\(^2\)   (b) 1.0j/cm\(^2\)   (c) 1.3j/cm\(^2\)   (d) 1.8j/cm\(^2\)
FIG. VII.6 CORROSION BEHAVIOR OF Cr-DEPOSITED LASER TREATED SPECIMENS FOR
(a) 0.6 J/cm²  (b) 1 J/cm²  (c) 1.3 J/cm²  (d) 1.8 J/cm²
The chromium was also found to be improving corrosion resistance in different acidic and alkali environments [Ashworth (1) et al., 1976]. Hence, we selected chromium metal for the current study.

In order to investigate whether any alloying element have beneficial, chromium was deposited on the as received maraging steel samples. In the FIG.VII.1b the aqueous behavior of corrosion for the samples deposited with chromium have been shown. The critical current density obtained in this case was +74 µA/cm². The active to passive transition took place at -470 mV electrode potential. The corrosion behavior similar to that of pure chromium was observed. It was also observed that no stable passive region occurred and dissolution mechanism was similar to that of as-received specimens. These results were found to be similar to the previous results. It is well known that a laser pulse with specific energies modifies the surface characteristics of metals and alloys [McCafferty et al., 1982]. Hence, the Chromium deposited and as-received specimens were laser treated at various energies ranging from .6 to 1.8 Joules. FIG.VII.5a, 5b, 5c, and 5d show the corrosion behavior of the laser treatment carried out on as received specimens at 0.6, 1.0, 1.3 and 1.8 J/cm² energy densities respectively.

The critical current densities of the corresponding laser energy treated samples were 94, 70, 79 and 75 µA/cm² respectively and active to passive transition took place at -470, -420, -472 and -490 mV electrode potentials respectively. In all these cases, no stable passive region was observed. Also the dissolution mechanism remained unaffected as compared with as-received specimen. But the critical current density comparatively decreased and passive potential increased. Particularly in case of laser treated sample with energy 1.3 J, the current density decreased by an order of three times as compared to that of the as-received specimens. This clearly indicates that the corrosion resistance of laser treated specimens with energy density 1.3 J/cm² increases. As for normal steel melting threshold was 1.2 J/cm² [Kulkarni et al., 1989] [Grum et al., 2006] [McCafferty, 1982], so for the maraging steel, we considered 1.3 J/ cm² as melting threshold, for large energy density (>1.3 J/cm²), the critical current density increased up to 1.8 J/cm² energy density. It was also observed that after passivation, there were no significant changes in both the laser treated and the as received specimens.

The electrochemical corrosion behavior of Cr-deposited laser treated specimens for laser energies .6, 1.0, 1.3 and 1.8 J is shown in FIG.VII.6a, 6b, 6c, and 6d respectively; their corresponding critical current densities were 34, 78, 110 and 32 µA/cm² respectively.
Passive potentials for corresponding energy densities were -510, -500, -520 and -490 mV respectively. Cr-deposited maraging steel irradiated at energy density of 0.6 and 1.8 J/cm\(^2\) showed improvement in corrosion resistance.

It was observed that the stable passive region occurred between -100 and +450 mV for the 1.3 J/cm\(^2\) irradiated samples. Thus similar to as-received laser irradiated sample (1.3J/cm\(^2\)), Cr-deposited and irradiated at same energy density, specimens showed melting threshold dependent variation. Though critical current density for 1.3 J/cm\(^2\) Cr-deposited irradiated sample was similar to that of as received specimen, corrosion resistance was improved due to the noble passive potential and stable passive region.

The SEM microphotograph of as-received laser irradiated maraging steel sample at energy dose of 1.3 Joules showed changes in surface characteristics [FIG.VII.7]. The surface morphology of the samples clearly showed slight roughness and pits at the surface.

The SEM image of Cr-deposited laser irradiated maraging steel sample at 1.8 J/cm\(^2\) is shown in FIG.VII.8. Most of the Chromium ions are mixed deep down the surface. The surface morphology changed much as compared to as received laser irradiated samples. Thus, melting and re-solidification allowed a redistribution of solute homogeneously, (no formation of the galvanic cells) rendering a smoother surface (decrease in surface area caused reduction in the current density) [Sinha, 1982] [Poornima (3), 2010].

CONCLUSIONS

It was concluded that laser irradiated specimens exhibited improved corrosion resistance as compared to the as-received and Cr-deposited specimens. Particularly in case of as-received laser treated sample with energy 1.3 J/cm\(^2\) and Cr-deposited laser irradiated sample with energy 1.8 J/cm\(^2\), the current density was decreased by an order of three times as compared to that of as-received specimens and two times that of Cr-deposited specimens. Thus, the corrosion resistance of laser treated specimens was increased. It can be concluded that the non-equilibrium technique, viz. laser irradiation surface processing technique, is a promising technique for improving the surface corrosive properties of maraging steel.
FIG. VII.7 SEM OF AS-RECEIVED LASER TREATED (1.3 J/cm²) SPECIMEN (A) BEFORE AND (B) AFTER CORROSION TREATMENT
(A) BEFORE                                     (B) AFTER
FIG. VII.8 SEM OF Cr-DEPOSITED LASER TREATED (1.8 J/ cm²)
SPECIMEN (A) BEFORE AND (B) AFTER CORROSION TREATMENT
VI.2.3 ION IMPLANTATION

Electro-chemical corrosion behavior of maraging steel after Krypton ion implantation using potentio-kinetic polarization technique:

The following different groups of maraging steel samples were studied for their electrochemical corrosion behavior [Shinde (3) et al., 2013] [Shinde (4), 2013].

a. As-received specimens.
b. Cr-deposited specimens.
c. As received specimens + Kr$^+$ ion implantation (implanted specimens).

Typical potentio-kinetic polarization behavior of above mentioned specimens have been shown in FIG.VII.1 (a), 1 (b) and FIG.VII.9 respectively. The variation in current with potential for ion implanted samples was studied using observed values [TABLE.VII.3].

FIG.VII.1 (a) shows electrochemical corrosion behavior of as-received maraging steel sample. The experiment was repeated for confirming the previous results obtained as well as confirming the conditions of buffer solution. It was observed that the active region was transformed to the passive region at the potential value of -545 mille volts. The characteristic critical current density at this point (point G) was +99 $\mu$A /cm$^2$. In this case, there was no stable passive region observed.

In order to investigate, whether alloying element have beneficial effect, the chromium was deposited on the as received maraging steel samples. The effect of deposition was similar to the previously observed effect and variation was found to be similar to the FIG.VII.1 (b).

The critical current density obtained in this case was 74 $\mu$A /cm$^2$. The active to passive transition was observed at -470 mV electrode potentials. The corrosion behavior similar to that of the pure chromium was observed [Shinde (5) et al., 2013] [Covino, 1971].

It was also observed that there is no stable passive region and the dissolution mechanism was similar to that of as-received specimens.

When the Krypton ions were incident on the surface of maraging steel specimens, the current-voltage relation was studied at different ion dose values (ranging from 1x10$^{14}$ - 1x10$^{16}$ ions/cm$^2$). FIG.VII. 9(a), 9(b), 9(c) and 9(d) shows corrosion behavior of implanted samples at doses of 1x10$^{14}$, 5x10$^{14}$, 1x10$^{15}$ and 1x10$^{16}$ ions/cm$^2$ respectively. Their corresponding critical current densities were 110, 114, 130 and 90 $\mu$A / cm$^2$ respectively.
TABLE VII.3: Average Critical current density and Average passive potential for various processed surfaces - ION IMPLANTATION

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specimen</th>
<th>Ion Implantation, Ion dose (ions/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>As-received</td>
<td>Cr-deposited</td>
</tr>
<tr>
<td>Critical current Density μA/cm²</td>
<td>99</td>
<td>74</td>
</tr>
<tr>
<td>Primary passive Potential (mV)</td>
<td>-545</td>
<td>-470</td>
</tr>
</tbody>
</table>
FIG.VII.9: ELECTROCHEMICAL CORROSION BEHAVIOR OF ION IMPLANTED SPECIMENS: (a) $1 \times 10^{14}$ ions/cm$^2$  
(b) $5 \times 10^{14}$ ions/cm$^2$  
(c) $1 \times 10^{15}$ ions/cm$^2$  
(d) $1 \times 10^{16}$ ions/cm$^2$
The active to passive transition took place at -478, -406, -480 and -500 mV values of electrode potential. The dissolution mechanism remained unchanged [Ashworth (1), 1976] [Ashworth (2), 1976].

A stable passive region was observed for specimen implanted at $5 \times 10^{14}$ ions / cm$^2$.

The region of passivity was found to be -150 and -650 mV, which is attributed to higher corrosion resistance. Also no formation of galvanic cell took place. The current density increase up to the certain point was found to be very slow after the passivation and after that point rate increases.

The scanning electron microscope image of ions implanted specimens at a particular dose value of the order of $5 \times 10^{14}$ ions per cm$^2$ is shown in FIG.VII.10. The surface morphology changed much as compared with the as received samples (FIG.VII.2). The redistribution of constituents takes place which in turn avoids corrosion of the maraging steel samples. It was observed that pit corrosion decreased due to ion implantation at particular dose values of $5 \times 10^{14}$ ions per cm$^2$.

**CONCLUSIONS**

Electrochemical corrosion behavior of as-received, Cr-deposited and ion implanted specimens was explained by using the polarization technique. It was found that ion implanted specimens exhibited improved corrosion resistance as compared to the as-received and Cr-deposited specimens. Thus, if we implant ions on the maraging steel specimens then the surface corrosive properties can be changed at specific dose values.

**VI.2.4 ION BEAM INDUCED ATOMIC MIXING**

The following different groups of maraging steel samples were studied for their electrochemical corrosion behavior.

a. As-received specimens.

b. Cr-deposited specimens.

c. Cr-deposited specimens + Kr$^+$ ion implantation (IBM specimens).

Typical potentio-kinetic polarization behavior of above mentioned specimens is shown in FIG.VII.1 (a), 1(b) and FIG.VII.11 respectively.
When the krypton ions were incident on the Cr-deposited specimens and corrosion behavior was observed, the potential and current values at critical point were as shown in the TABLE.VII.4.

The IBM specimens showed different corrosion effects for different ion doses (ranging from $1 \times 10^{16}$ - $3 \times 10^{16}$ ions/cm$^2$). The corrosion characteristics of IBM samples at doses of $1 \times 10^{16}$, $2 \times 10^{16}$ and $3 \times 10^{16}$ ions/cm$^2$ respectively has been shown in FIG.VII.11-a, 11-b and 11-c. Their corresponding critical current densities were 13, 19 and 23 µA/cm$^2$ respectively.

The active to passive transition took place at -261, -372 and -390 mV values of electrode potentials. It was observed that the dissolution mechanism remains unchanged and the critical current density for IBM samples was found to be 5 to 7 times less as compared with as received and Cr-deposited samples at initial selected ion dose value of $10^{16}$ ions per cm$^2$. Thus it was shown that IBM specimens have higher corrosion resistance than that of the implanted samples. This attributes to very high corrosion resistance of IBM specimens than that as received implanted samples of maraging steel [Shinde (4), 2013]. The dissolution mechanism remained unchanged and no formation of galvanic cell took place. Also no stable passive region formation observed. All ion beam mixed specimens showed that current density decreases. The comparison of observed ion doses showed that alloy formation by IBM process requires two times less ion dose than that required for alloy formation by ion implantation. This may be due to the fact that there is no sputtering effect in ion beam mixing process. Most of the chromium ions were mixed deep down the surface. The SEM microphotograph of the samples was found to be showing roughness and few pits at the surface due to clunging of the some chromium ions. The surface morphology of the samples clearly showed the roughness and few pits at the surface due to clunging of the some Cr ions. When specific ion beam mixed specimens (ion dose $1 \times 10^{16}$ ions per cm$^2$) were used for the electrochemical corrosion behavior in buffer solution of pH 7.3, The SEM photograph shown in FIG.VII.13 was obtained. It was observed that the surface morphology not changed much as compared with IBM treated sample before corrosion test (FIG.VII.12), and then also corrosion resistance was found to be improved. This was due to the fact that chromium ions along with other basic constituents get redistributed.
(A) BEFORE  
(B) AFTER  
FIG.VII.10: SEM OF ION IMPLANTED \((5 \times 10^{14}\, \text{ions/cm}^2)\) SPECIMENS  
(A) BEFORE AND (B) AFTER CORROSION TREATMENT
**TABLE VII.4:** Average critical current density and average potential for various surfaces-IBM

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specimen</th>
<th>Ion Beam Mixing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>As-received</td>
<td>Cr-deposited</td>
</tr>
<tr>
<td>Critical current Density</td>
<td>99</td>
<td>74</td>
</tr>
<tr>
<td>(µA/cm^2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary passive Potential</td>
<td>-545</td>
<td>-470</td>
</tr>
<tr>
<td>(mV)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
FIG.VII.11: ELECTROCHEMICAL CORROSION BEHAVIOR OF ION BEAM MIXED SPECIMEN

(a) $1 \times 10^{16}$ ions/c (b) $2 \times 10^{16}$ ion$^2$/cm$^2$ (c) $3 \times 10^{16}$ ions/cm$^2$
CONCLUSIONS

Electrochemical corrosion behaviors of as-received, Cr-deposited and IBM samples were observed and plotted by using the three sweep polarization technique. It can be concluded that IBM specimen’s exhibit improved corrosion resistance as compared to the as-received and Cr-deposited specimens. Thus it is possible to increase corrosion resistance five to seven times greater compared with other specimens at specific dose rate in an ion beam mixed process. The IBM technique seemed to be superior to other techniques.

VII.2.5 COMPARITIVE STUDY OF DIFFERENT TECHNIQUES:

The following different groups of maraging steel samples were studied for comparative study of electro chemical corrosion behavior [Shinde (1), 2013].

As-received specimens
a. Cr-deposited specimens.
b. As-received specimen + laser irradiation (1.3 J/cm²) (as-received laser irradiated specimens).
c. Cr-deposited specimen + laser irradiation (1.8 J/cm²) (Cr-deposited laser irradiated specimens)
d. As received specimens + Kr⁺ ion implantation (5x10¹⁴ ions/cm²) (implanted specimens).
e. Cr-deposited specimens + Kr⁺ ion implantation (1 x 10¹⁶ ions /cm²) (IBM specimens).

A potentio-kinetic polarization study of all the specimens was carried out to determine their characteristics critical current density and passivating potential. These two parameters are an overall indication of the relative general corrosion behavior of any material [Ashworth (1) et al., 1976]. In all these electrochemical measurements, a three sweep potentio-kinetic technique adopted by Ashworth et al. was used in order to avoid oxide film formation by air on the specimen surface. However, for simplicity only third positive going sweep is shown in all figures [Ashworth (2), 1976].
FIG. VI.12

FIG.VII.12 SEM IMAGE OF IBM TREATED (1x10^{16} ions/cm^2) SPECIMEN BEFORE CORROSION TEST

FIG.VII.13 SEM IMAGE OF IBM TREATED (1x10^{16}ions/cm^2) SPECIMEN AFTER CORROSION TEST
Typical potenio-kinetic polarization behavior of above mentioned specimens is shown in FIG.VII.1a, 1b, 5c, 6d, 9b and 11a respectively.

The current-voltage variation for as received, the chromium deposited, laser irradiated, ion implanted and ion beam mixed maraging steel specimens showed similarity in the graphical variation and hence the values at critical point of observation (point G) as given in TABLE.VII.5

Though there was no stability in the passive region, the chromium deposition can improve corrosion characteristics as shown by FIG.VII.1 (a) and FIG.VII.1 (b). The decrease in critical current density of Cr-deposited specimen (74 µA /cm$^2$) than as received specimens (99 µA /cm$^2$) indicated that we can minimize corrosion by depositing chromium metal.

It was also observed that dissolution mechanism was similar to that of as-received specimens [Foud, 2012]. But it seemed that chromium can act as inhibitor for corrosion to the 18% maraging steel [Cottrell et al., 1982]

The corrosion behaviors of as received, Cr-deposited, as received laser irradiated (1.3J/cm$^2$), Cr-deposited laser irradiated (1.8J/cm$^2$), ion implanted (5 x 10$^{14}$) ions per cm$^2$, and IBM specimens (1X10$^{16}$) ions/cm$^2$ were studied for confirmation and comparison of previous results. The corresponding critical current densities were 99, 74, 29, 32, 114 and 13 µA /cm$^2$ respectively. The active to passive transition took place at -545, -470, -472, -490, -406, and -261 mV values of electrode potentials respectively.

In case of as-received laser treated sample with energy 1.3 J/cm$^2$ and Cr-deposited laser irradiated sample with energy 1.8 J/cm$^2$, the current density was decreased by an order of three times as compared to that of the as-received specimens and two times that of Cr-deposited specimens. This clearly indicated that the corrosion resistance of particular laser treated specimen increases. It means that surface modification at this dose rate can form new metastable which phase prevents surface from corrosive environment in a larger way and can avoid stress corrosion cracking [Damborenea et al., 1998]. The major difference between the two curves was the hump on the positive potential side of the anodic loop of the Cr-deposited laser treated specimen, which indicated that passivating film breakdown occurs more easily on the Cr-deposited treated specimen than as received laser treated specimen.

In case of ion implanted specimen, a stable passive region was observed for specimen implanted at 5 x10$^{14}$ ions / cm$^2$. The region of passivity was found to be -150 and -650 mV, which was attributed to higher corrosion resistance.
**TABLE VII.5:** Average Critical current density and Average passive potential for various processed surfaces of Maraging steel

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specimen</th>
<th>Laser irradiation</th>
<th>Ion Implantation</th>
<th>Ion Beam Mixing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>As-received</td>
<td>Cr-deposited</td>
<td>Cr-deposited</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Laser irradiated 1.3J/cm²</td>
<td>Laser irradiated 1.8J/cm²</td>
<td></td>
</tr>
<tr>
<td>Critical current Density</td>
<td>99</td>
<td>74</td>
<td>29</td>
<td>32</td>
</tr>
<tr>
<td>(µA/cm²)</td>
<td></td>
<td></td>
<td></td>
<td>114</td>
</tr>
<tr>
<td>Primary passive Potential</td>
<td>-545</td>
<td>-470</td>
<td>-472</td>
<td>-490</td>
</tr>
<tr>
<td>(mV)</td>
<td></td>
<td></td>
<td></td>
<td>-406</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-261</td>
</tr>
</tbody>
</table>
Also no formation of galvanic cell took place. The implanted specimens showed very slow increase in the critical current density after passivation region. This effect may be due to the anodic dissolution in the negative region of the characteristics.

It was observed that after the negative characteristic region, the rate of dissolution rapidly increases with increase in passive potential and anodic current density. This effect can be compared by using the values of potentials -406 and -545 mV and current densities 114 and 99 µA/cm² of implanted and as received specimens respectively. The rate of anodic dissolution goes on increasing within the restricted region after the critical point (G).

The higher current density for implanted specimen than as received specimen may be attributed to the rough surface formation and hence increase in surface area of implanted sample.

The comparative study of IBM specimens with as received specimens can be done from the values of current and potential at specific ion dose rate. The critical current densities for IBM specimens (1 X 10¹⁶ ions per cm²) and as received specimens was 13 and 99 µA / cm². Thus there is very large decrease in critical current density (greater than seven) for IBM samples. The comparative study of SEM images of both samples showed that there was redistribution of constituent atoms. The composition of new alloy formed at surface resist the corrosion causing parameters. The chromium along with nickel and other atoms at the surface of specimen may be forming newer phases. According to the Ashworth et al. if we implant ions on the surface of iron base metals or alloys, the new transitions results and protective air formed film of magnetite is said to be present which increases corrosion resistance [Shinde (6) et al., 2013].

If we compare the results of ion implanted specimens with ion beam mixed samples using the variation, recorded values of current and potential and SEM of microphotographs then we can easily predict that the alloy formation at the surface by IBM process is advantageous than the direct implantation technique. The dose of ions required in ion implantation is at least two times higher than that required in IBM process for forming concentrated alloy at the surface. The surface composition always play important role.

The smoother surface was observed for IBM samples comparatively. The stability in passive potential region was also observed to be large with large decrease in critical current density (13 << 114 µA per cm²). The results themselves predicted the superiority of IBM technique.
The current-voltage variation, recorded results and microphotographs were used to compare the effects of IBM and laser irradiation on the specimens by considering specific dose values, corrosive properties and critical point conditions. The critical current densities for laser and IBM treated specimens were 29, 32 and 13 μA/cm$^2$ for the as received laser irradiated, Cr deposited laser irradiated and IBM specimens having specific dose values of 1.3 J/cm$^2$, 1.8 J/cm$^2$ and 1x10$^{16}$ ions / cm$^2$ respectively. The current density observed for ion beam mixed samples is two to three times less as compared with laser irradiated samples. The scanned surface images showed some pits on the as received laser irradiated specimens resulting in to increase in surface area than that of IBM samples under comparison. The pitting type corrosion can be minimized largely by using ion beam induced atomic mixing technique. The chromium ions were found to get mixed at deeper places of the surface. The Cr ions were found to be attached with other ions.

Scanning Electron Microscope photographs of the above specimens have been shown in FIG.VII.2, 3, 4, 7, 8, 10, 12, and 13. The graphical results were confirmed by using the surface morphological photographs. The surface morphology of the Cr-deposited samples clearly showed the smoothness and few pits as compared to the as-received maraging steel samples as shown in FIG.VII.3. The surface morphology showed that chromium deposition preserves the surface of as-received maraging steel samples by increasing corrosion resistance.

The SEM microphotograph of as-received laser irradiated maraging steel sample as in FIG.VII.7 and Cr-deposited laser irradiated maraging steel sample at 1.8 J/cm$^2$ as in Fig.VII.8 clearly showed slight roughness and pits at the surface. Most of the chromium ions are mixed deep down the surface. The surface morphology changed much as compared to as received laser irradiated samples. It has previously been shown that the oxide film on untreated iron chromium alloys cannot be completely reduced cathodically [Cottrell et al., 1982]. Since the oxide films on both the treated samples are approximately of equal thickness, the lower cathodic and anodic currents on the Cr-deposited specimen’s most likely result from a lower ionic and electronic conductivity of the oxide, due to its enrichment in chromium. The laser irradiation on the as received specimens introduces strains and defects into melt layer, resulting in faster pit growth and a change in pit morphology compared to that observed for Cr-deposited laser irradiated specimens.
The SEM photograph of ion implanted sample (FIG.VII.10) showed that the surface morphology changed much compared with as received samples (FIG.VII.2). The redistribution of constituents takes place which in turn avoids corrosion of the maraging steel samples. Thus we can avoid corrosion due to the pitting effect, if the implantation is carried out only at specific dose rate of $5 \times 10^{14}$ ions/cm$^2$.

When IBM samples were treated at specific dose value under electrochemical corrosion behavior in the buffer solution of pH 7.3, the SEM photograph shown in FIG.VII.13 was obtained. The crystallographic pits in the implanted specimen nucleate on ridges, where melt spot overlap. Nucleation most likely occurred at points of stress that arise at the sites exposed to multiple events. Micro photograph clearly showed that, as these pits grow, their bottom becomes flat. The smaller of the two pits has a flat bottom, while the larger one is flat at its periphery but has deepened slightly in the center and appears to be changing its morphology as it deepens. This phenomenon of reduced growth rate normal to the surface and change in morphology was also observed when this alloy with a mechanically polished surface was pitted under the same conditions [Shinde (7), 2013]. In the present study, the implanted surface was deformed or damaged by transient thermo-mechanical stresses that introduced defects, like those caused due to mechanical polishing. As a result pitting occurs at a faster rate with a different morphology in the melt layer than in the annealed bulk. The depth of the smaller pit is similar to the melt depth. Surface morphology of the samples clearly showed the roughness and few pits at the surface due to clinging of the some Cr-ions at the interface.

**VII.3 ANTIMICROBIAL ACTIVITY**

Results of the microbial analysis of water samples are presented in TABLE VII.6, TABLE VII.7, TABLE VII.8, and FIG VII.14 (A) and 14 (B). A water sample examined in this study showed pH 6.7. It was observed that water sample contained four different bacterial isolates viz. *Legionella pneumophila*, *Shigella sonnei*, *Campylobacter jejuni* and *Aeromonas hydrophila*. These isolates were identified and confirmed, based on the selective, differential media and biochemical tests [Holt et al., 1994] [Shinde (5), 2013].
### ANTIMICROBIAL ACTIVITY

**TABLE VII.6: Bacteria identified in Manchar town Water supply**

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Isolate No.</th>
<th>Bacteria – Species Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Isolate 1</td>
<td><em>Legionella pneumophila</em></td>
</tr>
<tr>
<td>2</td>
<td>Isolate 2</td>
<td><em>Shigella sonnei</em></td>
</tr>
<tr>
<td>3</td>
<td>Isolate 3</td>
<td><em>Campylobacter jejuni</em></td>
</tr>
<tr>
<td>4</td>
<td>Isolate 4</td>
<td><em>Aeromonas hydrophila</em></td>
</tr>
</tbody>
</table>
TABLE VII.7: Antibacterial activity of as-received and Cr-deposited samples for different bacterial isolates (inhibitory zone in mm diameter by subtracting disc diameters)

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Name of Organism/Isolate No.</th>
<th>Antibiotics</th>
<th>Control sample (as received)</th>
<th>Cr-deposited sample</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Ampicillin</td>
<td>Tetracycline</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Isolate 1</td>
<td>0</td>
<td>12</td>
<td>8</td>
</tr>
<tr>
<td>2</td>
<td>Isolate 2</td>
<td>12</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>Isolate 3</td>
<td>11</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>4</td>
<td>Isolate 4</td>
<td>9</td>
<td>8</td>
<td>4</td>
</tr>
</tbody>
</table>
TABLE VII.8: Conformation of identified bacteria:

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Characteristics</th>
<th><em>Legionella pneumophila</em></th>
<th><em>Shigella sonnei</em></th>
<th><em>Campylobacter jejuni</em></th>
<th><em>Aeromonas hydrophila</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Gram reaction</td>
<td>Negative</td>
<td>Negative</td>
<td>Negative</td>
<td>Negative</td>
</tr>
<tr>
<td>2</td>
<td>Cell shape</td>
<td>Straight Rod</td>
<td>Rod</td>
<td>Helical</td>
<td>Short rod</td>
</tr>
<tr>
<td>3</td>
<td>Motility</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>4</td>
<td>Catalase test</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Acid from glucose</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Indole from tryptophan</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Hydrolysis of</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1) Casein</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2) Gelatin</td>
<td></td>
<td></td>
<td></td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>3) Starch</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4) Urea</td>
<td></td>
<td></td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>10</td>
<td>Methyl red</td>
<td>-</td>
<td>+</td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>11</td>
<td>Voges proskauer</td>
<td>-</td>
<td>-</td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>12</td>
<td>malonate</td>
<td>-</td>
<td>-</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>13</td>
<td>Oxydase</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>
FIG.VII.14 (A) IDENTIFICATION OF BACTERIA

Isolate 1. *Legionella pneumophila*  Isolate 2. *Shigella sonnei*

FIG.VII.14 (B) IDENTIFICATION OF BACTERIA

a. *L. pneumophila*  
b. *S. sonnai*  
c. *Campilobacter jejuni*  
d. *A. hydrophila*
VII.4 IDENTIFIED BACTERIA IN THE MANCHAR TOWN WATER SUPPLY

The bacteria detected and or identified in the laboratory in the drinking water have been studied by using standard information and procedure. The detection or identification had been performed by different investigators at different places. But, there is no any literature available about the identification of bacteria in the drinking water of Manchar town water supply. Following bacteria are detected [Holt et al., 1994].

VII.4.1 *Aeromonous hydrophila*:

**Scientific classification**

1. The domain of these classes is Bacteria.
2. Its kingdom is Proteobacteria
3. It belongs to Grammaproteobacteria Phylum
4. The class of these bacteria is Aeromonaldes and is generally called as *A. hydrophilas* species.
5. The binomial name is *Aerominas hydrophila*
6. The synonyms to these species are
7. *Bacillus hydrophilus*
8. *Pseudomonas hydrophila*
9. *Bacillus hydrophilus fuscus*
10. *Bacterium hydrophilum*

These bacteria are motile and may grow in the environment having temperature as low as 4 °C. The shape is in the form of rods with rounded ends. The width of the bacteria is 0.3 to 1 micrometer and length is of the order of 1-3 micrometer.

The toxicity of the bacteria is familiar due to its structure. These bacteria are opportunistic and can enter easily in the healthy human body. The tissue damage takes place after production of Arolysin Cytotoxic Enterotoxin. This type of pathogens is usually considered as fish and amphibian pathogens. It is well known that they are very toxic in nature because of their specific structure. They can travel through bloodstream of the victim. The young children
and persons who have comprised immune systems, fishermen and the persons living near dam water are easily affected by this bacterium [Bragga et al., 1990].

VII.4.2 *Campylobacter jejuni*

According to the scientific classification

1. They belong to the Kingdom of Bacteria.
2. Their phylum is Proteobacteria and belongs to the class of Epsilon Proteobacteria.
3. The order is Campylobacterales and their family as the Campylobacteraceae.
4. The genus is *Campylobacter* are characterized by *C. Jejuni* species.
5. The binomial name of these bacteria is *Campylobacter Jejuni*

These bacteria are helical in shape and curved nature. They are Gram negative micro-aerophilic and non spore forming [Ryan et al., 2004]. They cause gastroenteritis’s. Whenever there is food poisoning, *Campylobacter* species are observed in pathological reports. They get distributed through contaminated drinking water as well as through unpasteurized milk efficiently. The sources of bacteria are incorrectly prepared meat, contaminated food product and dirty poultry. It colonizes the digestive tracts of many birds.

The *C. jejuni* causes enteritis. This is characterized by abdominal pain, diarrhea and changing fever [Colles et al., 2009]. Food poisoning is linked with Guillian Bare syndrome development. After the initial illness, it is developed two to three weeks latter which also threaten life. *C. jejuni* only grow on the plates because the colonies are oxydase positive. The erythromycin resists these species. The campylobacteriosis is caused in calves. These can be isolated from kangaroo feces. The temperature requirement for Campylobacter species is found to be 42 °C. In addition, instead of using usual normal agar, we can use blood agar for growing [Parkhil et al., 2000].

VII.4.3 *Shigella sonnei:*

1. As per scientific classification, they belong to the Kingdom of the Bacteria.
2. Their phylum of protobacteria and are from class of Gamma Protobacteria.
3. Their order is Enterobacteriales belong to the family of Enterobactericeae.
4. They are from the *Shigella* genus and are called as *Shigella sonnei.*
5. Their binomial name is *Shigella sonnei*.

It is a Gram negative and non-motile bacterium. This is also non spore forming and facultative anaerobic. These species have not flagella for the facilitating its movement. The shape of bacteria is like long rods. They can grow in 37 °C optimal environmental temperature. Their natural host is gastrointestinal tract. The *S. sonnei* is always transmitted through contaminated water and uncooked food [Selma, 2007]. The shiga toxin formed constitutes bacteria’s. Such toxin affects neurons and cytoplasm of cells. In soil linen, these bacteria are survived up to seven weeks. Their survival in fresh water environment lasts for 30 hours. Generally they are spread through fecal oral transmission.

The classifications have been done by considering the O-antigen component of the LSP involved in the outer membrane of the bacteria [Niyogi et al., 2005] [Seol, 2006].

These can be evolved from the strains of *E. coli* [Yang et al., 2005]. Most of the shigellosis cases are related with these bacteria though there is very small amount of contaminated water [Shiferaw et al., 2004]. The *S. sonnei* genome is very dynamic compared with another bacterium. This may be due to the DNA rearrangement. The plasmid characteristic about this bacterium is well known. When these enter the human body symptoms observed is high fever, malaise and tenesmus. The research study on bioactivity of food plant showed that the ozone can become inactive by these bacteria [Selma et al., 2007].

**VII.4.4 Legionella pneumophila**

**Scientific Classification**

1. These bacteria belong to the kingdom of Bacteria.
2. Their class is Gamma Proteobacteria and order is Legionellaceae.
3. They are characterized by genus *Leginella* and *L. pneumophila* species.
4. Their binomial name is *Legionella pneumophila*.

This was found to be gram negative and having a polar flagellum. It is usually non capsulated. They always reside in aquatic environments. If grown on the nutrient deficient media then they become long and filament type. They live like intracellular parasites. There residence and transmission is constitutes potable water distribution system. *L. pneumophila* are found to be not much sensitive to some antibiotics e.g.
penicillin, cephalosporin etc. Pneumonia caused by these bacteria is not curable easily [Lederberg et al., 2000]. It is treated only with antibiotics such as tetracycline’s, quinolones etc

The survey taken by different researchers reported that Logionellaceae in the intracells is the main cause of hidden pneumonia. The genome detected was found to be having circular nature. These bacteria can interact with environmental conditions [Stout et al., 1985]. If there is facility of spa baths then there is possibility of very large outbreak of Legionellosis. The urinary antigen detection and molecular epidemiology study performed was shown that the infection sources are resulted from contaminated water sources [Kavano et al., 2007].

The co-evolution of these species as fresh water amoebae had been observed [Cazalet et al., 2004]. In the HIV infected patients study revealed that L. pneumophila was more severe. The higher mortality rate was observed in affected patients [Garcia et al., 2007]. The AID’s caused patients are found to be more sensitive to be more sensitive to these species. The natural hosts are found to be Amoebae [Pedro-Botet et al., 2007].

VII.5.0 Antibacterial activity of As-received / Control sample:

The antimicrobial activity observations of as received maraging steel (Control sample) were noted in the TABLE.VII.6 and TABLE.VII.7 and the corresponding photographs (FIG.VII.15) were taken. It was observed that the diameters of inhibitory zone’s for Ampicillin were (0, 12, 11 and 9), for Tetracycline were (12, 2, 3, and 8) and for as received samples were (8, 8, 6 and 4 mm); for all four isolates respectively. It was found that Legionella pneumophila are resistive (diameter 0 mm) to the Ampicillin but susceptible (diameter 12 mm) to the Tetracycline and as received maraging steel (diameter 8 mm). The identified bacteria Shigella sonnei, Campylobacter jejuni and Aeromonas hydrophila were found to be susceptible to the Ampicillin and Tetracycline antibiotics. The diameters of inhibitory zones for control sample are found to be smaller than that for Ampicillin corresponding to Isolate 2, 3, and 4. It means control samples are less susceptible to Isolate 2, 3 and 4 but more susceptible to Isolate 1 (Legionella pneumophila) than Ampicillin. These experimental observations clearly showed that as received maraging steel samples possess antibacterial property.
FIG.VII.15.A: ANTIMICROBIAL ACTIVITIES OF MARAGING STEEL AGAINST

*L. pneumophila*
FIG.VII.15.B: ANTIMICROBIAL ACTIVITIES OF MARAGING STEEL AGAINST S. sonnai
FIG. VII.15.C: ANTIMICROBIAL ACTIVITIES OF MARAGING STEEL AGAINST

*C. jejuni*
FIG.VII.15.D: ANTIMICROBIAL ACTIVITIES OF MARAGING STEEL AGAINST

A. hydrophila
Antimicrobial activities of Cr-deposited maraging steel as compared to control.

**FIG.VII.15.E ANTIMICROBIAL ACTIVITIES OF Cr-DEPOSITED MARAGING STEEL:** For different isolates

- a. *L. pneumophila*
- b. *S. sonnai*
- c. *Campilobacter jejuni*
- d. *A. hydrophila*
VII.5.1 Antibacterial activity of Cr-deposited sample:

Bacteria identified in Manchar town water supply have been given in TABLE.VII.6 and identified bacteria are shown in FIG.VII.14. Antibacterial activity of as received and Cr-deposited sample for different bacterial isolates has been given in TABLE.VII.7 and shown in FIG VII.15.A, FIG VII.15.B, FIG VII.15.C, FIG VII.15.D, and FIG VII.15.E.

It was observed that the diameter of inhibitory zone’s for as received samples (8, 8, 6 and 4 mm) were higher than that for Cr-deposited samples (2, 6, 4 and 2 mm) for all four isolates. Particularly for *L. pneumophila* and *Shigella sonnei* were found to be highest (both 8 mm).

These experiments clearly showed that as received maraging a steel and Cr-deposited sample possesses antibacterial property. The identified bacteria *Shigella sonnei, campylobacter jejuni* and *Aeromonas hydrophila* were found to be susceptible to the Ampicillin and Tetracycline antibiotics. It was also found that *Legionella pneumophila* are resistive (diameter 0 mm) to the Ampicillin but susceptible (diameter 12 mm) to the Tetracycline.

VII.5.2 Antibacterial activity of as-received laser irradiated samples:

Antibacterial activity of as received laser irradiated samples for different bacterial isolates has been given in TABLE.VII.9 and shown in FIG.VII.16

It was observed that the diameter of inhibitory zones for as received laser irradiated samples ( energy density 1.3 J/cm$^2$) for different bacterial isolates were higher (11, 9, 10 and 7 mm) than that for as received (8, 8, 6 and 4 mm) and Cr-deposited samples (2, 6, 4 and 2 mm) for all four isolates. Particularly for energy density 1.3 J/cm$^2$, diameter of zones was found to be highest (11mm) for *Legionella pneumophila* isolate. As like antibiotics, *L. pneumophila* showed susceptible nature to the as received laser irradiated samples, because of the surface ions property, the samples acted as an inhibitor to these bacteria. The observations showed that as energy of the dose increases the diameter if inhibitory zone went on increasing up to 1.3 J and beyond this dose there is decrease in diameter of the zone. All the bacteria were susceptible to the as received laser irradiated specimen is the important result.
**TABLE.VII.9: Antibacterial activity of as received laser irradiated samples for different bacterial isolates (inhibitory zone in mm diameter by subtracting disc diameters)**

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Name of Organism/Isolate No.</th>
<th>Antibiotics</th>
<th>Control sample (as received)</th>
<th>Cr-deposited sample</th>
<th>As received laser irradiated samples (energy density in J/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Ampicillin</td>
<td>Tetracycline</td>
<td></td>
<td>0.6 1.0 1.3 1.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Diameter in mm</td>
</tr>
<tr>
<td>1</td>
<td>Isolate 1</td>
<td>0</td>
<td>12</td>
<td>8</td>
<td>2 4 6 11 8</td>
</tr>
<tr>
<td>2</td>
<td>Isolate 2</td>
<td>12</td>
<td>2</td>
<td>8</td>
<td>6 3 4 9 6</td>
</tr>
<tr>
<td>3</td>
<td>Isolate 3</td>
<td>11</td>
<td>3</td>
<td>6</td>
<td>4 6 7 10 2</td>
</tr>
<tr>
<td>4</td>
<td>Isolate 4</td>
<td>9</td>
<td>8</td>
<td>4</td>
<td>2 2 3 7 5</td>
</tr>
</tbody>
</table>
Antimicrobial activities of Laser irradiated maraging steel as compared to control.

FIG.VII.16 ANTIMICROBIAL ACTIVITIES OF LASER IRRADIATED MARAGING STEEL: For different isolates

a. *L. pneumophila*  b. *S. sonnai*

c. *Campilobacter jejuni*  d. *A. hydrophila*
The susceptible nature of bacteria to these samples may be dependent on the corrosion resistance and due to the redistribution of the elements at the surface.

**VII.5.3 Antibacterial activity of Cr-deposited laser irradiated samples:**

Antibacterial activity of as received laser irradiated samples for different bacterial isolates has been given in TABL.VII.10 and shown in FIG.VII.17

It was observed that the diameter of inhibitory zone diameters for Cr-deposited laser irradiated samples for different bacterial isolates were higher (10, 6, 4, 5 mm) than that for as received (8, 8, 6 and 4 mm) and Cr-deposited samples for all four isolates (2, 6, 4 and 2 mm). Particularly for energy density 1.8 J/cm², diameter of zones was found to be highest (10mm) for *Legionella pneumophila* isolate. As like as received laser irradiated samples, these samples also showed the increase in diameter of inhibitory zones with increase in corrosion resistance. Thus from both the observations it is clear that the antibacterial activity depends on the corrosion resistance of the maraging steel samples for laser treatment.

**VII.5.4 Antibacterial activity of as received ion implanted samples:**

Antibacterial activity of as received ion implanted samples for different bacterial isolates has been given in TABLEVII.11 and shown in FIG.VII.18

It was observed that the diameter of inhibitory zones of as received samples for different bacterial isolates were in general higher (8, 8, 6 and 4 mm) than that of as received ion implanted (6, 8, 4 and 3 mm) and Cr-deposited samples (2, 6, 4 and 2 mm) for all four isolates. The ion implanted samples at dose value 5 X 10¹⁴ ions / cm² was found to be having highest (8 mm) diameter for *Shigella sonnei* isolates. The observations showed that direct implantation of ions on the surface of base material is not much advantageous.
TABLE VII.10: Antibacterial activity of Cr-deposited laser irradiated samples for different bacterial isolates (inhibitory zone in mm diameter by subtracting disc diameters)

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Name of Organism/Isolate No.</th>
<th>Antibiotics</th>
<th>Control sample (as received)</th>
<th>Cr-deposited sample</th>
<th>Cr-deposited laser irradiated samples (energy density in J/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.6 1.0 1.3 1.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ampicillin</td>
<td>Tetracycline</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Isolate 1</td>
<td>0</td>
<td>12</td>
<td>8</td>
<td>2 3 6 7 10</td>
</tr>
<tr>
<td>2</td>
<td>Isolate 2</td>
<td>12</td>
<td>2</td>
<td>8</td>
<td>6 2 5 6 6</td>
</tr>
<tr>
<td>3</td>
<td>Isolate 3</td>
<td>11</td>
<td>3</td>
<td>6</td>
<td>4 2 2 5 4</td>
</tr>
<tr>
<td>4</td>
<td>Isolate 4</td>
<td>9</td>
<td>8</td>
<td>4</td>
<td>2 5 4 3 5</td>
</tr>
</tbody>
</table>
FIG. VII.17 ANTIMICROBIAL ACTIVITIES OF Cr-DEPOSITED LASER IRRADIATED MARAGING STEEL: For different isolates

a. *L. pneumophila*  b. *S. sonnai*

c. *Campilobacter jejuni*  d. *A. hydrophila*
### TABLE VII.11: Antibacterial activity of ion implanted samples (inhibitory zone in mm diameter by subtracting disc diameters)

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Name of Organism/Isolate No.</th>
<th>Antibiotics</th>
<th>Control sample (as received)</th>
<th>Cr-deposited sample</th>
<th>Ion implanted samples (ion dose in ions/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Ampicillin</td>
<td>Tetracycline</td>
<td></td>
<td>1x10^{14}</td>
</tr>
<tr>
<td>1</td>
<td>Isolate 1</td>
<td>0</td>
<td>12</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>Isolate 2</td>
<td>12</td>
<td>2</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>Isolate 3</td>
<td>11</td>
<td>3</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>Isolate 4</td>
<td>9</td>
<td>8</td>
<td>4</td>
<td>2</td>
</tr>
</tbody>
</table>
Antimicrobial activities of ion implanted maraging steel as compared to control.

**FIG.VII.18 ANTIMICROBIAL ACTIVITIES OF ION IMPLANTED MARAGING STEEL: For different isolates**

- a. *L. pneumophila*
- b. *S. sonnai*
- c. *Campilobacter jejuni*
- d. *A. hydrophila*
### TABLE VII.12: Antibacterial activity of IBM samples for different bacterial isolates (inhibitory zone in mm diameter by subtracting disc diameters)

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Name of Organism/Isolate No.</th>
<th>Antibiotics</th>
<th>Control sample (as received)</th>
<th>Cr-deposited sample</th>
<th>Ion Beam mixed samples (ion dose ions/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Ampicillin</td>
<td>Tetracycline</td>
<td></td>
<td></td>
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<tr>
<td>1</td>
<td>Isolate 1</td>
<td>0</td>
<td>12</td>
<td>8</td>
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<tr>
<td>2</td>
<td>Isolate 2</td>
<td>12</td>
<td>2</td>
<td>8</td>
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<tr>
<td>3</td>
<td>Isolate 3</td>
<td>11</td>
<td>3</td>
<td>6</td>
<td>4</td>
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<tr>
<td>4</td>
<td>Isolate 4</td>
<td>9</td>
<td>8</td>
<td>4</td>
<td>2</td>
</tr>
</tbody>
</table>

The inhibitory zone in mm diameter by subtracting disc diameters for each isolate is as follows:

- Isolate 1: 9 mm
- Isolate 2: 9 mm
- Isolate 3: 5 mm
- Isolate 4: 8 mm
Antimicrobial activities of Ion Beam Mixed (IBM) maraging steel as compared to control.

FIG.VII.19 ANTIMICROBIAL ACTIVITIES OF ION BEAM MIXED (IBM) MARAGING STEEL AND Cr-DEPOSITED SPECIMENS:

For different isolates

a. *L. pneumophila*  
b. *S. sonnai*  
c. *Campylobacter jejuni*  
d. *A. hydrophila*
VII.5.5 Antibacterial activity of IBM samples:

Antibacterial activity of as received IBM samples for different bacterial isolates has been given in TABLE VII.12 and shown in FIG. VII.19.

It was observed that the diameters of inhibitory zones for IBM samples of different bacterial isolates were higher (9, 9, 5 and 8 mm) than that of as received (8, 8, 6 and 4 mm) and Cr-deposited samples for all four isolates (2, 6, 4 and 2 mm). Particularly for ion dose $1 \times 10^{16}$ ions /cm$^2$, the diameters were found to be highest for *Legionella pneumophila* and *Shigella sonnei* (both 9 mm).

The antimicrobial activity observed for antibiotics dominated the results. The bacteria were very susceptible to the samples The IBM samples showed advantageous property e.g. antimicrobial activity.

VII.5.6 Comparative study:

Antibacterial activity of samples has been given in TABLE VII.13 and FIG. VII.20. The treated samples for selected comparative study were found to be having large corrosion resistance as discussed in the first part of this chapter.

It was observed that the diameters of inhibitory zones of as received laser irradiated samples for energy 1.3 J/cm$^2$ for bacterial isolates, *L. pneumophila*, *S. sonnei*, *C. jejuni* and *A. hydrophila*, were higher (11mm, 9 mm, 10 mm and 7 mm) than that of as received (8, 8, 6 and 4 mm), Cr-deposited (2, 6, 4 and 2 mm), Cr-deposited laser irradiated, and ion implanted samples. The diameters of zones for this laser energy density for isolates *L. pneumophila*, and *C. jejuni* were found to be greater than that of IBM samples. The antimicrobial activities of IBM samples (for ion dose $1 \times 10^{16}$ ions /cm$^2$) i.e. diameters of inhibitory zones (9 mm, 9 mm, 5 mm and 8 mm) were greater than that of as received, Cr-deposited, Cr-deposited laser irradiated and ion implanted samples. Thus as-received laser irradiated (energy 1.3 Joules) and IBM (for ion dose $1 \times 10^{16}$ ions /cm$^2$) samples of maraging steel were found to be very effective to destroy all the four bacterial isolates identified or present in the drinking water of Manchar town like water supplies.
TABLE.VII.13: Comparative study of Antibacterial activity of different samples for different bacterial isolates (inhibitory zone in mm diameter by subtracting disc Diameters)

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Name of Organism / Isolate No.</th>
<th>Antibiotics</th>
<th>Control sample or As-received</th>
<th>Cr-deposited sample</th>
<th>As received laser irradiated samples</th>
<th>Cr-deposited laser irradiated samples</th>
<th>Ion implanted sample Ion dose (ions/cm²)</th>
<th>IBM sample Ion Dose (ions/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Ampicillin</td>
<td>Tetracycline</td>
<td></td>
<td>1.3 J/cm²</td>
<td>1.8 J/cm²</td>
<td>5x10^{14}</td>
<td>1x10^{16}</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td>1.3 J/cm²</td>
<td>1.8 J/cm²</td>
<td>5x10^{14}</td>
<td>1x10^{16}</td>
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<td>Isolate 2</td>
<td>12</td>
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<td>Isolate 3</td>
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</tbody>
</table>
FIG.VII.20 ANTIMICROBIAL ACTIVITIES OF LASER IRRADIATED, Cr DEPOSITED LASER IRRADIATED, ION IMPLANTED, AND IBM SPECIMENS FOR *L. pneumophila*