Studying of influence of a neutron irradiation on element contents and structures of aluminum alloys SAV-1 and AMG-2

U. S. Salikhbaev, S. A. Baytelesov, F.R. Kungurov, A. S. Saidov

It is one of fundamental problems in the sphere of the study of construction materials for nuclear reactors to create a radiation-resistant material fit for long-term operation under high-dose neutron radiation conditions. At present, SAV-1 and AMG-2 aluminum alloys are used at the WWR-M reactors as fuel elements which differ from other alloys with their physical and mechanical properties, specifically, super-durability, corrosion resistance and high reserve of creepage.

This work is devoted to a study into the influence of neutron radiation on the elemental composition and structure of SAV-1 and AMG-2 alloys. With this aim in view the samples of these alloys were exposed to neutron flux at the WWR-SM reactor at the Institute of Nuclear of Physics of the AS of the RUz, using the fluencies of $\approx 10^{19}$ neutron/sm².

Measurement of neutron flux spectrum

- Monitors Au, Co, Ni, Ti, Fe have been made from thin roll flat metal foil, and Y and Mg were taken in the form of their connections MgO and Y2O3.

- Two sets of monitors have been weighed, packed into polyethylene packages, wrapped in aluminum foil and soldered in quartz ampoules. One of ampoules has been soldered in Cd glass for cut-off by component thermal flux in the course of irradiation of monitors. Irradiation of both containers was carried out consistently in the current of 2 hours in the second channel of the reactor general neutrons flux. Measurement of samples’ gamma activity was carried out in 3-10 days after irradiation. Registration of samples gamma spectrum was carried out on HP Ge detector with multichannel analyzer DSA1000 of Canberra firm, processing of gamma spectrum was carried out by means of standard software package Genie 2000.

### Table 1. Description of monitors

<table>
<thead>
<tr>
<th></th>
<th>%</th>
<th>$E_n$, MeV</th>
<th>$T1/2$, d</th>
<th>$E$, KeV</th>
<th>M, mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{197}\text{Au}(n,\gamma)^{198}\text{Au}$</td>
<td>100</td>
<td>2.7d</td>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>$^{58}\text{Ni}(n,p)^{58}\text{Co}$</td>
<td>67.88</td>
<td>2.6</td>
<td>71.3d</td>
<td>810.8(99)</td>
<td>12.25</td>
</tr>
<tr>
<td>$^{24}\text{Mg}(n,p)^{24}\text{Na}$</td>
<td>78.7</td>
<td>6.3</td>
<td>15.05h</td>
<td>1368.5(100)</td>
<td>1.1457</td>
</tr>
<tr>
<td>$^{48}\text{Ti}(n,p)^{48}\text{Sc}$</td>
<td>73.94</td>
<td>7</td>
<td>1.83d</td>
<td>1312.1(100)</td>
<td>15.15</td>
</tr>
<tr>
<td>$^{46}\text{Ti}(n,p)^{46}\text{Sc}$</td>
<td>7.93</td>
<td>4.5</td>
<td>83.89d</td>
<td>889.2(100)</td>
<td>15.15</td>
</tr>
<tr>
<td>$^{54}\text{Fe}(n,p)^{54}\text{Mn}$</td>
<td>5.84</td>
<td>3</td>
<td>312.6d</td>
<td>834.8(100)</td>
<td>9.05</td>
</tr>
<tr>
<td>$^{89}\text{Y}(n,2n)^{88}\text{Y}$</td>
<td>100</td>
<td>12</td>
<td>108.1d</td>
<td>898.92(92)</td>
<td>5.9842</td>
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<tr>
<td>$^{60}\text{Ni}(n,p)^{60}\text{Co}$</td>
<td>26.23</td>
<td>6</td>
<td>5.26y</td>
<td>1173.2(100)</td>
<td>12.25</td>
</tr>
</tbody>
</table>
Neutron flux density in reactor channel in energy interval from 0.025 eV until 12 MeV

![Graph](image)

**Table 2. Experiment results of fast neutron flux in the reactor (Ni-58, optical absorption)**

<table>
<thead>
<tr>
<th>#</th>
<th># channels</th>
<th>Ni-58 $10^{-12}$</th>
<th>optical absorption</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7-1</td>
<td>1.89</td>
<td>0.4</td>
</tr>
<tr>
<td>2</td>
<td>4-1</td>
<td>4.78</td>
<td>0.65</td>
</tr>
<tr>
<td>3</td>
<td>5-1</td>
<td>6.39</td>
<td>0.9</td>
</tr>
<tr>
<td>4</td>
<td>6-1</td>
<td>4.15</td>
<td>0.96</td>
</tr>
<tr>
<td>5</td>
<td>3-7</td>
<td>10.12</td>
<td>1.18</td>
</tr>
<tr>
<td>6</td>
<td>7-3</td>
<td>10.02</td>
<td>1.15</td>
</tr>
<tr>
<td>7</td>
<td>2-4</td>
<td>4.98</td>
<td>1.52</td>
</tr>
<tr>
<td>8</td>
<td>4-2</td>
<td>17.52</td>
<td>1.44</td>
</tr>
<tr>
<td>9</td>
<td>6-2</td>
<td>12.03</td>
<td>1.57</td>
</tr>
<tr>
<td>10</td>
<td>6-7</td>
<td>10.36</td>
<td>1.65</td>
</tr>
</tbody>
</table>

In the table 3, shows calculation results neutron flux spectrum using MCNP4c code.

**Table 3. Calculation results neutron flux spectrum**
<table>
<thead>
<tr>
<th># Channel</th>
<th>Energy MeV</th>
<th>Flux n/sm²·s</th>
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</thead>
<tbody>
<tr>
<td>1-4</td>
<td>0 - 6,2500E-07</td>
<td>1.33244E+14</td>
</tr>
<tr>
<td></td>
<td>6,2500E-07 - 8,0000E-01</td>
<td>3.95490E+13</td>
</tr>
<tr>
<td></td>
<td>8,0000E-01 - 3,0000E+00</td>
<td>7.47058E+12</td>
</tr>
<tr>
<td></td>
<td>3,0000E+00 - 2,0000E+01</td>
<td>1.81057E+12</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>1.82074E+14</td>
</tr>
<tr>
<td>2-5</td>
<td>0 - 6,2500E-07</td>
<td>1.97076E+14</td>
</tr>
<tr>
<td></td>
<td>6,2500E-07 - 8,0000E-01</td>
<td>1.36796E+14</td>
</tr>
<tr>
<td></td>
<td>8,0000E-01 - 3,0000E+00</td>
<td>3.20508E+13</td>
</tr>
<tr>
<td></td>
<td>3,0000E+00 - 2,0000E+01</td>
<td>8.09698E+12</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>3.74019E+14</td>
</tr>
<tr>
<td>6-2</td>
<td>0 - 6,2500E-07</td>
<td>1.54672E+14</td>
</tr>
<tr>
<td></td>
<td>6,2500E-07 - 8,0000E-01</td>
<td>1.33735E+14</td>
</tr>
<tr>
<td></td>
<td>8,0000E-01 - 3,0000E+00</td>
<td>3.12010E+13</td>
</tr>
<tr>
<td></td>
<td>3,0000E+00 - 2,0000E+01</td>
<td>8.57388E+12</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>3.30102E+14</td>
</tr>
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</table>

Definition of crystal structure and parameter of a lattice of alloys was spent on X-ray diffractometer DRON-3M (λ=0.15418 nanometers).

According to the radiographic analysis as expected, initial alloys SAV-1 and AMG-2 have face-centered cubic arrangement with lattice parameter, a = 4.066 ± 0.003 Å and a = 4.0726±0.003 Å, accordingly. Small increase of alloys’ lattice parameter in comparison with the reference aluminum sample of (4.0414 Å) is result from the presence of impurity in them.

To determine the elemental composition and structure of the samples, the latter were studied with the help of the micro analyzer “Jeol” JSM 5910 IV- Japan. Tables 4 and 5 summarize contents (%) of the elements Mg, Al, Fe, Si and Cu for the alloys SAV-1 and AMG-2, correspondingly, before and after the samples were subjected to \(10^{19}\) neutron/cm² fluencies. It is worth noting that data in Table 4 coincides with published data for the SAV-1 and AMG-2 samples. In addition, the tables contain the measurement data only for those points which fail to appear in the area of local formations of insoluble intermetal phases. Tables 4 and 5 present screened illustration of the samples SAV-1 for elements Mg, Al, Fe and Si before and after irradiation with the fluence of \(10^{19}\) neutron/cm², correspondingly. Fig. 2 shows local formations by way of white stains of insoluble inter-metal phases of the of type Al-Mg-Si-Fe with the size of 1 - 10 mkm (for example, see Fig. 2 for Si). The measurement of the element content at these two points has given the following result: Point I: Al = 66.72%; Mg = 11.06%; Si = 15.80%; Fe = 5.96%. Point II: Al = 69.70%; Mg = 4.88%; Si = 13.37%; Fe = 11.63%.

It is seen in Fig.3 that after being irradiated, the surface of the sample is oxidized and the local insoluble intermetal phases of the type of Al-Mg-Si-Fe are broken up and scattered over a large volume of the sample becoming actually evenly distributed over all the volume. It is especially well-seen on the bitmap pictures (Fig. 3) of the elements Fe and Mg. Such a breaking up of the local insoluble intermetal phases in the final analysis has caused a considerable change in the elemental composition in the three points measured which is seen in Table 5. It seems that a considerable change in the size of the local insoluble intermetal phases causes a change in the
thermal conductivity, specific resistance, as well as microhardness of the samples when the latter have been subjected to irradiation. The further investigations will be devoted to determination of the above-mentioned characteristics of the samples.

Table 4
Elemental composition of the main admixtures (%) in the SAV-1 and AMG-2 samples before being irradiated with a neutron flux

<table>
<thead>
<tr>
<th>Sample</th>
<th>№</th>
<th>Mg</th>
<th>Al</th>
<th>Si</th>
<th>Mn</th>
<th>Fe</th>
<th>Cu</th>
<th>Total</th>
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</thead>
<tbody>
<tr>
<td>SAV-1</td>
<td>1</td>
<td>1,00</td>
<td>98,42</td>
<td>0,45</td>
<td>0,00</td>
<td>0,14</td>
<td>0,00</td>
<td>100,00</td>
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<tr>
<td>SAV-1</td>
<td>2</td>
<td>1,04</td>
<td>98,24</td>
<td>0,54</td>
<td>0,00</td>
<td>0,13</td>
<td>0,06</td>
<td>100,00</td>
</tr>
<tr>
<td>SAV-1</td>
<td>3</td>
<td>1,15</td>
<td>98,12</td>
<td>0,51</td>
<td>0,02</td>
<td>0,14</td>
<td>0,06</td>
<td>100,00</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>1,06</td>
<td>98,26</td>
<td>0,50</td>
<td>0,01</td>
<td>0,14</td>
<td>0,04</td>
<td>100,00</td>
</tr>
<tr>
<td>AMG-2</td>
<td>4</td>
<td>2,81</td>
<td>96,72</td>
<td>0,00</td>
<td>0,21</td>
<td>0,27</td>
<td>0,00</td>
<td>100,00</td>
</tr>
<tr>
<td>AMG-2</td>
<td>5</td>
<td>2,77</td>
<td>96,65</td>
<td>0,00</td>
<td>0,27</td>
<td>0,25</td>
<td>0,07</td>
<td>100,00</td>
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<tr>
<td>AMG-2</td>
<td>6</td>
<td>2,82</td>
<td>96,72</td>
<td>0,00</td>
<td>0,24</td>
<td>0,23</td>
<td>0,00</td>
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<tr>
<td>Average</td>
<td></td>
<td>2,80</td>
<td>96,70</td>
<td>0,00</td>
<td>0,24</td>
<td>0,25</td>
<td>0,02</td>
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</table>

Table 5
Elemental composition of the main admixtures (%) in the SAV-1 sample after being irradiated with the fluence of $10^{19}$ neutron/cm$^2$

<table>
<thead>
<tr>
<th>Sample</th>
<th>№</th>
<th>Mg</th>
<th>Al</th>
<th>Si</th>
<th>Fe</th>
<th>Cu</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAV-1</td>
<td>1</td>
<td>0,48</td>
<td>96,33</td>
<td>2,72</td>
<td>0,44</td>
<td>0,04</td>
<td>100,00</td>
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<tr>
<td>SAV-1</td>
<td>2</td>
<td>0,57</td>
<td>97,42</td>
<td>1,77</td>
<td>0,25</td>
<td>0,00</td>
<td>100,00</td>
</tr>
<tr>
<td>SAV-1</td>
<td>3</td>
<td>0,55</td>
<td>97,054</td>
<td>1,66</td>
<td>0,27</td>
<td>0,00</td>
<td>100,00</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>0,53</td>
<td>97,09</td>
<td>2,05</td>
<td>0,32</td>
<td>0,01</td>
<td>100,00</td>
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<tr>
<td>AMG-2</td>
<td>4</td>
<td>1,230,57</td>
<td>97,51</td>
<td>0,58</td>
<td>0,68</td>
<td>0,00</td>
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<td>AMG-2</td>
<td>5</td>
<td>1,56</td>
<td>97,204</td>
<td>0,56</td>
<td>0,68</td>
<td>0,00</td>
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<tr>
<td>AMG-2</td>
<td>6</td>
<td>1,71</td>
<td>97,32</td>
<td>0,57</td>
<td>0,31</td>
<td>0,09</td>
<td>100,00</td>
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<tr>
<td>Average</td>
<td></td>
<td>1,50</td>
<td>97,34</td>
<td>0,57</td>
<td>0,56</td>
<td>0,03</td>
<td>100,00</td>
</tr>
</tbody>
</table>
Fig. 2. Microstructure of SAV-1 initial alloy (before irradiation)
Fig. 3. Microstructure of SAV-1 alloy after irradiation with $10^{19}$ n/cm$^2$ fluence
Microhardness measurement shows, that it is observed strong enough dependence $H \mu$ from weight to value $F \approx 3$ N. On weights $F > 3$ N microhardness practically does not depend on weight. As depth of penetration of diamond pyramid depends on weight, it is possible to draw a conclusion, that in surface layer of samples at microhardness definition, apparently plays essential role.

Fig. 4. Neutron irradiated SAV-1 alloy samples’ microhardness dependence from loading on indentor: not irradiated (1); irradiated by fluences $10^{18}$ cm$^{-2}$ (3) and $10^{19}$ cm$^{-2}$ (2)

Fig. 5. Neutron irradiated AMG-2 alloy samples’ microhardness dependence from loading on indentor: not irradiated (2); irradiated by fluences $10^{18}$ cm$^{-2}$ (2) and $10^{19}$ cm$^{-2}$ (3)

Essentially increase of size after irradiation fluence 1017 n/sm2 and rather poorly linearly grows at the further increase fluence almost in all range of loading $F > 3$ N, that microhardness essentially increases at the first irradiation. Essential reduction of the sizes
(smashing) and dispersion of local insoluble intermetallic phases on big volume of alloys after irradiations and radiating defects, on the visible lead to additional fastening of dispositions that causes increase in microhardness of samples.

Fig. 6. AMG-2 (▲) and SAV-1 (●) alloys microhardness dependence form neutron fluence. Points marked for comparison corresponding to $H_\mu$ values of not irradiated AMG-2 (▲) and SAV-1 (○)

**Conclusion**

- Influence of reactor irradiations various fluences ($10^{17} - 10^{21}$ n/sm$^2$) on a microstructure and microhardness of alloys SAV-1 and AMG-2 is studied. It is revealed, that reactor irradiation leads to practically uniform redistribution of the basic impurity on all sample, before irradiation there was non-uniform distribution in initial samples because of natural ageing.
- In the interval we have found fluence swelling is insignificant.
- It is established, that under the influence of irradiation microhardness of alloys essentially increases at primary irradiation before fluence $10^{17}$ n/sm$^2$ and linearly grows at the further increase fluences to $10^{21}$ n/sm$^2$. The microhardness increase results from smashing and dispersion local insoluble intermetallic system Al-Mg-Si-Fe phases on great volume of alloys and growth of concentration of radiation defect with increase of fluence.

**REFERENCES**


