

Part II

Was the “Critical Evidence” presented in the South Korean Official Cheonan Report Fabricated?

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The official Cheonan report [1] presented two “critical scientific evidences” that link the sinking of the South Korean navy corvette Cheonan to the alleged explosion of a North Korean torpedo: the now-infamous “No. 1” ink mark on the torpedo, and the EDS and x-ray data of the three “adsorbed materials” extracted from the ship, the torpedo and a small-scale test-explosion, respectively. In our previous paper [2], we pointed out that the EDS and x-ray data are self-contradicting. Here we report our SEM, EDS, and x-ray experiments on an Al powder that underwent melting and quenching. Our results show that their EDS data of the two samples from the ship and torpedo must be fabricated. Therefore, until the South Korean Joint Investigation Group (JIG) can convince the international scientific communities with their story, their official conclusion that the torpedo sank the Cheonan ship should be discarded.

Let us start with the key claims made in the Cheonan report and our main conclusions.

Key claims made in the CheonAn report by the Korean CIV-MIL JIG:

- (a)** Chemical and structural properties of the following three samples of “adsorbed material” (AM) were investigated using Electron-Dispersive Spectroscopy (EDS) and x-ray diffraction: (i) the first sample, here referred to as AM-I, was extracted from the surface of the bow, stern, stack of the CheonAn ship; (ii) the second sample, AM-II, was extracted from the surface of the propeller of the torpedo; (iii) the third sample, AM-III, was from the inner surface of the Al plate used to cover the top of the metal tank that housed enough ocean water and used a small scale test explosion.
- (b)** The sample AM-III that was attached to the Al top plate after the test explosion must be explosive-turned material.
- (c)** The EDS data of all three samples were almost identical, with similar strengths of aluminum signal. This confirms that the first two samples, AM-I and AM-II, are also explosive-turned material.

- (d) However, the X-ray diffraction patterns of the AM-I and AM-II samples taken from the CheonAn ship and from the torpedo did not exhibit at all any signature of aluminum or any oxidized Al material.
- (e) The complete lack of any Al-related x-ray signals in the two samples, AM-I and AM-II, is in fact pivotal evidence that the torpedo exploded and sank the CheonAn ship. It is because during the explosion 100 % of the aluminum melted and supercooled into an amorphous Al-oxide, and an amorphous material does not produce a distinct X-ray diffraction pattern.
- (f) The “adsorbed materials” that was attached on the propeller of the torpedo and on the CheonAn ship were determined to be identical. This leads to our conclusion that the torpedo explosion sank the corvette CheonAn.

Summary of our simulations of their x-ray data [2], and our own SEM, EDS and x-ray measurements on a heated and quenched Al sample reported here

- (a) Their EDS and x-ray data are self-contradicting.
- (b) As explained in our previous paper [2], there are two scenarios that may explain the discrepancy of the EDS and x-ray data in the Cheonan report.
 - The first scenario: the AM-III sample obtained from the test-explosion is not related to explosive but it is mostly the Al powders that are scratched off from the Al top plate. This can explain the x-ray data. However, their claim, i.e., the same EDS data of the three samples indicate the AM-I and AM-II are explosive, is no longer valid.
 - The second scenario: the AM-III sample is mostly the explosive-related material. If this is the case, its x-ray data tells that even after the explosion the crystalline aluminum rather than the amorphous aluminum oxides should be dominant. Thus, similar sharp Al-peaks should have been observed in the x-ray data of the AM-I and AM-II. But they are not.
- (c) We have performed SEM, EDS, and x-ray measurements on two crystalline Al samples, one without heat treatment and another with heat and quenching treatment.
- (d) Our EDS and x-ray data are more or less consistent with those of their test-explosion sample: during heating and rapid quenching Al oxidizes only partially, and furthermore the resulting Al and Al_2O_3 are crystalline rather than amorphous.

(e) Thus, the second scenario mentioned in (b) is correct. This leads us to conclude that the EDS data of their first and second samples were fabricated.

Our SEM, EDS and X-ray Data and Discussion

In order to distinguish the two aforementioned scenarios, we have performed SEM (scanning electron microscopy), EDS (electron dispersive spectroscopy) and x-ray measurements on the following two samples: (1) an Al powder without heat treatment and (2) an Al powder that was heated at 1100 °C for 40 min and quenched in water in less than 2 sec.

Here we minimally describe the experimental procedure. For the details, see the Supplementary Information attached to the end of this report.

A very fine powder of crystalline Al with 300 mesh, i.e., a maximum grain size of $\sim 1 \text{ inch}/300 \sim 85 \mu\text{m}$, was chosen to maximize the oxidization during the experiment. We prepared two Al samples. Before the measurements, one sample, let say Al-I, was just taken out of the sample bottle without any heat treatment, while the other sample, Al-II, was put in a horizontal furnace, and heat up to 1100 °C that is well above the melting temperature of Al, 660 °C, and stayed at that 1100 °C for ~ 40 minutes, before it was taken out quickly and put into a jar of water. The procedure of taking out and putting it into the water took less than 2 seconds. (see the Supplementary Information).

Each sample was divided into two portions: a larger amount that was used for the x-ray measurement and a smaller amount used for the SEM/EDS.

The x-ray portion was placed on a glass plate, while the EDS portion was placed on a carbon tape that was attached to a small carbon circular plate. (see the Supplementary Information) The pictures of the x-ray and the EDS machine, and the loading of the samples were shown in the Supplementary Information. One thing to remember is that x-ray penetrates into the sample about a few hundreds μm while EDS penetrates only about several μm . Thus, EDS probes the atomic composition of the surface of the sample while x-ray probes the chemical material composition of the sample in bulk.

Fig. 1 (a)-(c) show the SEM images and the EDS data obtained from the first sample, Al-I. Fig. 1 (a) shows the SEM image, exhibiting the Al-I grains with typical sizes of $\sim 10 \mu\text{m}$ to $\sim 100 \mu\text{m}$. Fig. 1 (b) is a close-up of one large grain whose EDS data is shown in Fig. 1 (c). The EDS data of Al-I clearly exhibits the Al peak at around 1.5 keV. And there are no other peaks, except the signal of the carbon coated to give electrical conductivity for the measurements. Other grains also gave similar EDS data. On the other hand, its x-ray data (Fig. 2 (a)) exhibit only the pure Al Bragg peaks, which indicates that as expected the amount of Al_2O_3 is negligible in this untreated crystalline Al powder sample.

Fig. 1 (d)-(f) show the SEM images and the EDS data of the heat-treated and quenched second sample, Al-II. The SEM images (Fig. 1 (d) and (e)) are much shinier than those of the Al-I sample (Fig. 1 (a) and (b)). This tells that the surfaces of the metallic Al grains are oxidized into the insulating Al_2O_3 from which the incident electrons are reflected rather than penetrating into the sample. Thus, the shiny SEM images indicate that oxidization occurred during the heating and quenching.

Now, the questions that arise are (1) how much Al has been oxidized during the heat treatment, and (2) in which form, crystalline or amorphous, the resulting oxidized Al and/or the remaining Al exist afterward. X-ray data will give us the answers.

As shown in Fig. 2 (b), the x-ray data of the heat-treated sample, Al-II, exhibit two sets of well-defined sharp Bragg peaks from crystalline Al and crystalline Al_2O_3 . This clearly indicates that **(1) Al oxidizes partially** not entirely during the heating and rapid quenching, and that **(2) after the quenching the Al and the oxidized Al_2O_3 become crystalline** rather than amorphous! Our refinement of the data tells us that $\sim 40\%$ of the Al has oxidized during the heat treatment. When compared with the x-ray data of the test-explosion sample, AM-III, presented in the official Cheonan report, in the test-explosion the amount of oxidized Al is much smaller than the 40% oxidization observed here. We believe that it is because in our experiment the Al sample was above its melting temperature for ~ 40 minutes that is much longer than it would have during an explosion. Of course, the amount of the oxidized Al would depend on other factors as well such as the amount of oxygen in the surroundings, but from our heat-treatment results and their test-explosion results, one can safely say that the duration of the sample above its melting point is the most crucial, and the 40% is probably close to the maximum oxidization fraction for an explosion. This was proved by their test-explosion (see below).

What are the implications of our results to the EDS and x-ray data of the three “adsorbed materials” that were presented as one of the two “critical scientific evidence” in the South Korean official Cheonan report? **(1)** Our EDS and x-ray data of the heat-treated sample, Al-II, are similar to those of the “adsorbed material”, AM-III, taken from their test-explosion [1,2]: in EDS, both Al and O signals were observed, and in x-ray, strong Bragg peaks from crystalline Al and much weaker Bragg peaks from crystalline Al_2O_3 were present. This means that their EDS and x-ray of the test-explosion sample are more or less correct (except the relative strength of the Al and O EDS signals). In other words, the sample AM-III was indeed explosive-turned material. **(2)** Thus, among the two possible scenarios to explain the inconsistency of their data, the second scenario is correct. In other words, their first and second samples extracted from the Cheonan ship and the torpedo should have exhibited similar sharp Al and Al_2O_3

Bragg peaks. But they did not. How can one then explain their EDS data that show the Al signal as strong as that observed in the third test-explosion sample? The only explanation is that the Al signal was not real but was put in by hands. In other words, the EDS data of their first and second “adsorbed materials” were fabricated.

Why did they do that? If we ignore the Al signal in the EDS data, then the EDS and x-ray data become consistent: the samples contains mainly NaCl (salt from ocean water) and SiO₂ (from sand). Thus, one can conclude that the two “adsorbed materials”, extracted from the Cheonan ship and torpedo, are nothing but salt and sand. The two “adsorbed materials” have nothing to do with an explosion. And the x-ray data were correctly collected and presented: no trace of Al or Al₂O₃. The EDS data would not have shown any Al signal. To make their case that the two samples are explosive-related materials, the Al signal was added by hands. This is the only scientifically sensible explanation. We challenge the South Korean JIG to provide their own scientifically sensible explanation for their data. Until they can convince the international scientific communities with their story, their official conclusion that the torpedo sank the Cheonan ship should be discarded.

Acknowledgement

We thank Representative MoonSoon Choi for providing the information, and a few people for discussion and for help with the SEM, EDS and x-ray measurements.

References

- [1] The Cheon-An report by the Korean CIV-MIL JIG (Min-Goon Joint Investigation team) that was partially released very recently to the members of the Congressional Cheon-An committee. Representative Choi, MoonSoon, provided us the report.
- [2] S.-H. Lee, *Comments on the Section “Adsorbed Material Analysis” of the Cheonan Report made by the South Korean Civil and Military Joint Investigation Group (CIV-MIL JIG)*, arXiv:1006.0680v2 (<http://arxiv.org/abs/1006.0680>).

Figures

Fig. 1. SEM and EDS data of (a)-(c) the untreated Al sample and (d)-(f) the melted and rapidly quenched Al sample. (a), (b), (d) and (e) are the SEM images. (c) and (f) are the EDS data.

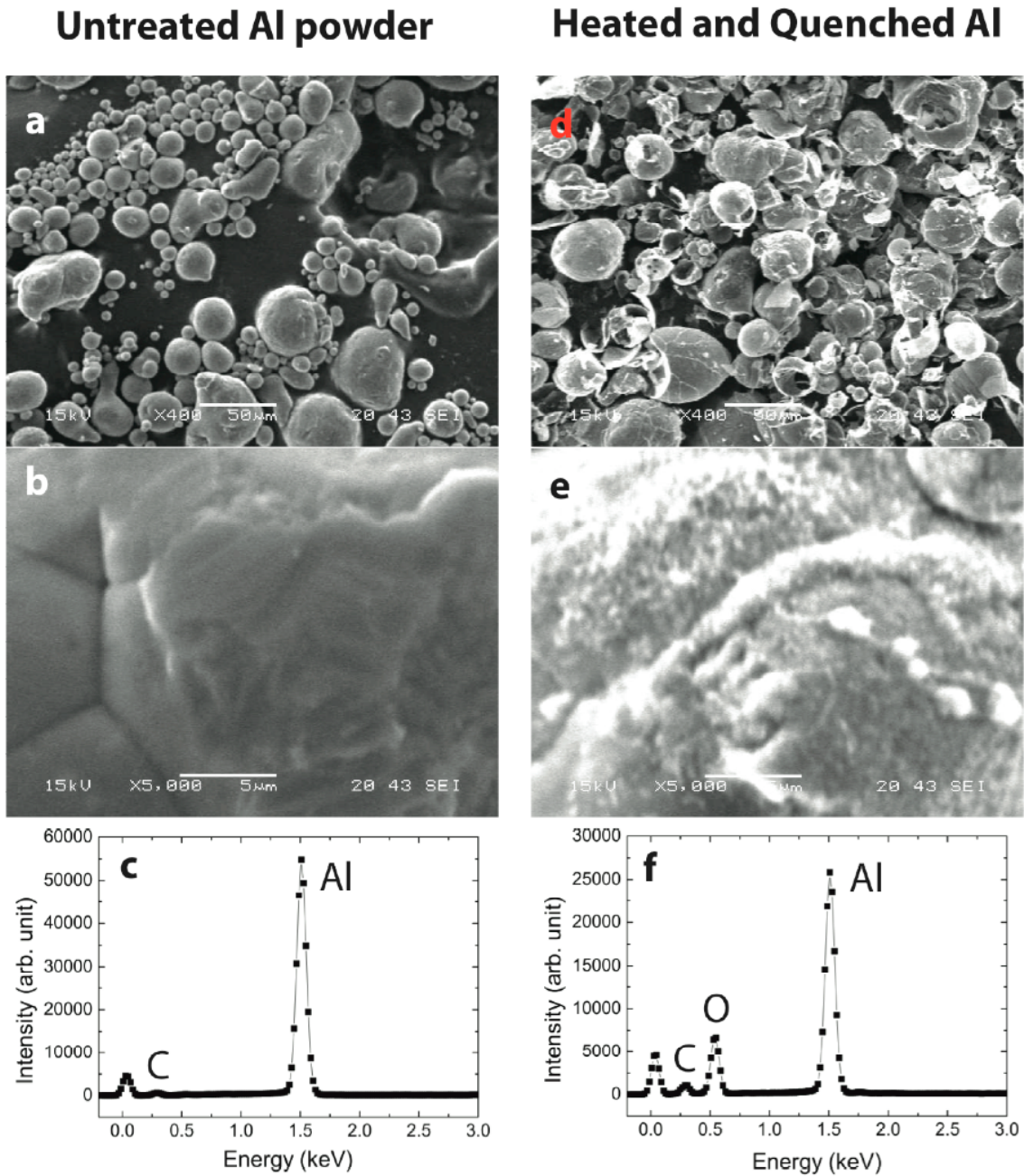
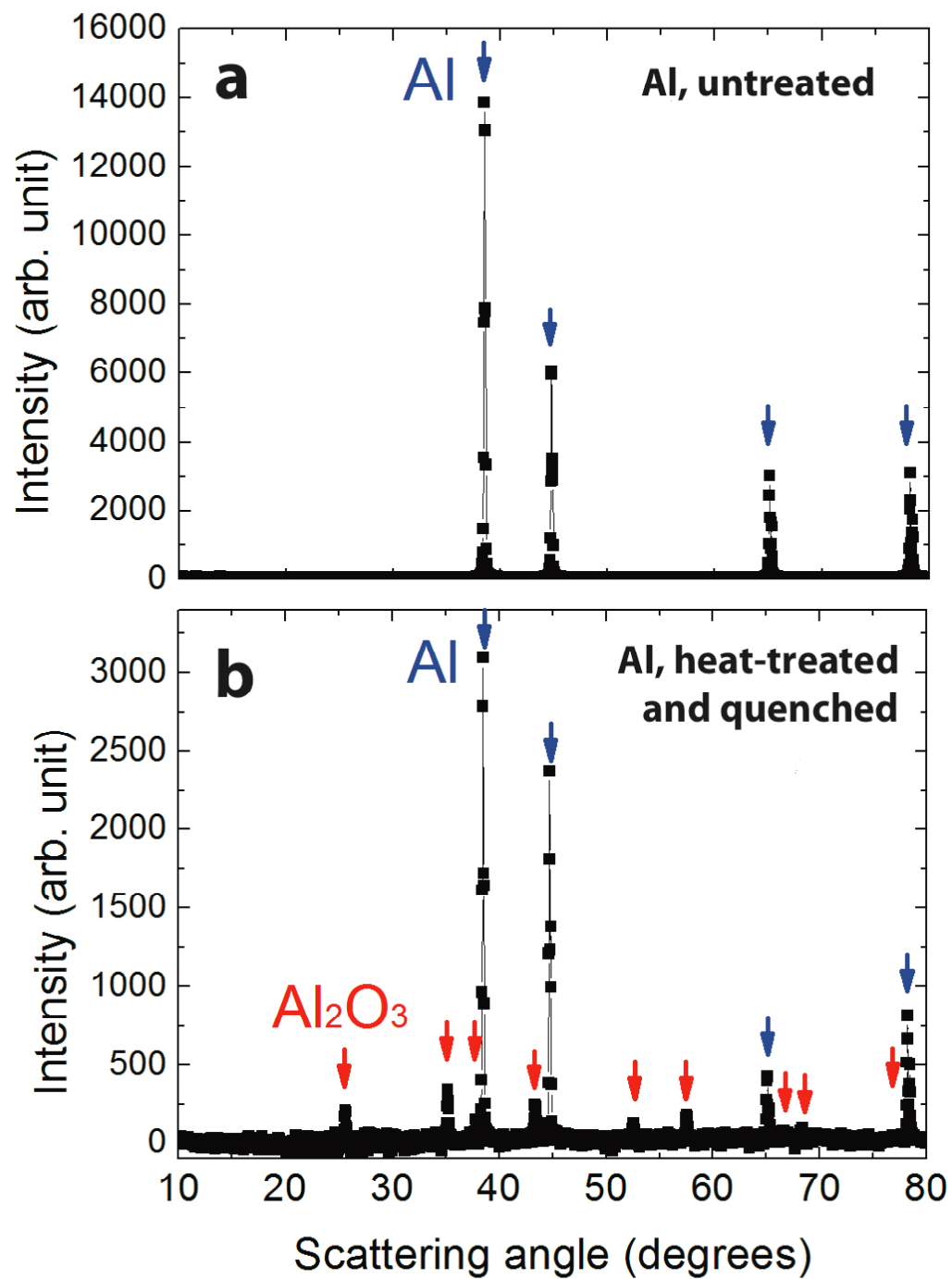


Fig. 2. X-ray data of (a) the untreated Al sample and (b) the melted and rapidly quenched Al sample.



Appendix:

Part I

Comments on the Section “Adsorbed Material Analysis” of the CheonAn Report made by the South Korean Civil and Military Joint Investigation Group (CIV-MIL JIG)

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On the night of March 26, 2010, the 1,200 ton South Korean (ROK) Navy corvette Cheonan sank in the Yellow Ocean (or China Ocean) at the closest point of South Korean territory to the North. Forty-six crew members died. On May 20, 2010, ROK announced, based on a ROK-sponsored investigation, that the corvette Cheonan was sunk by a North Korean (DPRK) torpedo. We have examined the “critical scientific evidence” of “adsorbed materials” that was presented to support their conclusion. On the contrary to their claim, our analysis of their electron-dispersive spectroscopy (EDS) and x-ray data show that the data are self-contradicting, to say the least. Our findings clearly show that the validity of their data and interpretations, and the ROK’s conclusion are highly questionable.

When a government announces they reached a conclusion based on “overwhelming scientific evidence” that can lead to grave consequences in the international stage, it is our duty, as scientists, to check the validity of their data, interpretations, and thus their conclusions. More often than not, on closer inspection the “scientific evidence” turns out to be mediocre and sometimes self-contradicting. Recently, we have obtained from South Korean Congressman, Choi, MunSoon, the section “Adsorbed Material Analysis” of the official Cheonan report and carefully examined it. Before discussing their data, let us first summarize their claims and the results of our analysis.

Key claims made in the CheonAn report by the Korean CIV-MIL JIG:

- (g)** Chemical and structural properties of the following three samples of “adsorbed material” (AM) were investigated using Electron-Dispersive Spectroscopy (EDS) and x-ray diffraction: (i) the first sample, here referred to as AM-I, was extracted from the surface of the bow, stern, stack of the CheonAn ship; (ii) the second sample, AM-II, was extracted from the surface of the propeller of the torpedo; (iii) the third sample, AM-III, was

from the inner surface of the Al plate used to cover the top of the metal tank that housed enough ocean water and used a small scale test explosion.

- (h) The sample AM-III that was attached to the Al top plate after the test explosion must be explosive-turned material.
- (i) The EDS data of all three samples were almost identical, with similar strengths of aluminum signal. This confirms that the first two samples, AM-I and AM-II, are also explosive-turned material.
- (j) However, the X-ray diffraction patterns of the AM-I and AM-II samples taken from the CheonAn ship and from the torpedo did not exhibit at all any signature of aluminum or any oxidized Al material.
- (k) The complete lack of any Al-related x-ray signals in the two samples, AM-I and AM-II, is in fact pivotal evidence that the torpedo exploded and sank the CheonAn ship. It is because during the explosion 100 % of the aluminum melted and supercooled into an amorphous Al-oxide, and an amorphous material does not produce a distinct X-ray diffraction pattern.
- (l) The “adsorbed materials” that was attached on the propeller of the torpedo and on the CheonAn ship were determined to be identical. This leads to our conclusion that the torpedo explosion sank the corvette CheonAn.

Problems

- (f) Our own analysis shows that the X-ray data of the AM-III sample from the test-explosion is dominated by crystalline Al, which is strikingly different from the AM-I and AM-II data. This difference, however, was not explained in their report.
- (g) There are two ways to explain the discrepancy.
 - The first possibility: the AM-III sample obtained from the test-explosion is not related to explosive but it is mostly the Al powders that are scratched off from the Al top plate. This can explain the x-ray data. However, their claim (c), i.e., the same EDS data of the three samples indicate the AM-I and AM-II are explosive, is no longer valid.
 - The second possibility: the AM-III sample is mostly the explosive-related material. If this is the case, its x-ray data tells that even after the explosion the crystalline aluminum rather than the amorphous aluminum oxides should be dominant. Thus, similar sharp Al-peaks should have

been observed in the x-ray data of the AM-I and AM-II. But they are not.

(h) This discrepancy cannot be explained scientifically.

(d) Furthermore, our simulations show that even if 100 % Al turned to amorphous Al_2O_3 during the explosion, it should have been seen in their x-ray measurements, contrary to their claim.

Data and Discussion:

The small scale test explosion was performed by a SK government laboratory. During the experiment, the chemical and structural properties of the following three samples were characterized [1],

- (1) An “absorbed material” which was found on the bow, stern, stack of the sunk CheonAn ship. The experimental data obtained from this sample were labeled as “Bow, Stern, Stack” in the report, but here let us call it AM-I.
- (2) A similar “absorbed material” found on the propeller of the torpedo. Its experimental data were labeled as “Critical evidence” in the report, but here let us simply call it AM-II.
- (3) A similar “absorbed materials” extracted “after” explosion from the inner surface of the Al plate that covered the metal box in which the experiment was performed. Its data were labeled “UNDEX Experiment” in the report, but here let us call it AM-III.

The purpose of the test was to prove (1) that the AM-I and AM-II are the same material, which implies, even though not necessarily correct, they came from the same origin, and (2) that the AM-III is the same material as the AM-I and AM-II. If these two points turned out to be true, then they can very well be interpreted as a “critical evidence” that the explosion of the torpedo racked the corvette Cheonan.

Now let us turn to their actual data.[1]

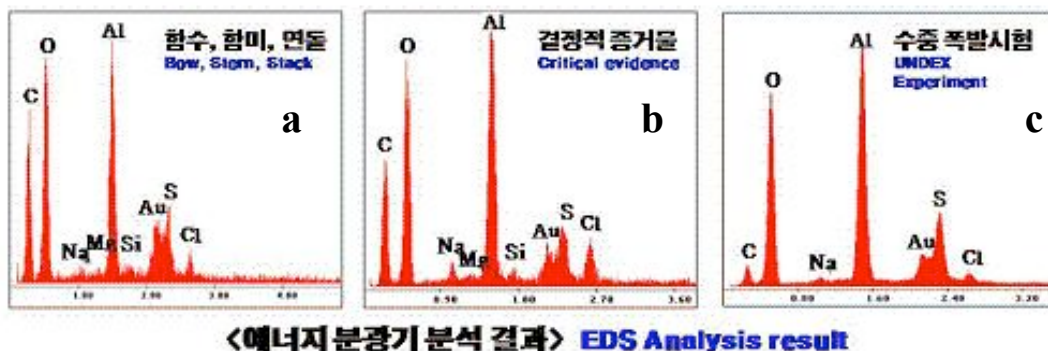


Fig. 1. The reported EDS data obtained **a**, from AM-I, the absorbed material extracted from the “bow, stern, and stack” of the Cheon-An ship, **b**, from AM-II, “critical evidence”, extracted from the propeller of the torpedo, and **c**, from AM-III, “UNDEX Experiment”, extracted from the mock-up torpedo after explosion. The horizontal and vertical axes represent the energy and strength of the signal, respectively. This figure was taken from Ref. [1].

The EDS data shown in Fig 1 clearly indicate that the three samples contain the identical atoms, C, O, Na, Al, Au, S, Cl, except that Si is not detectable in the

검출 물질 Extracted	함량(%) Content	비고 Notes	검출 물질 Extracted	함량(%) Content	비고 Notes
알루미늄 산화물(Al_2O_3)	45~55	비결정 Amorphous	황 Sulfur	3.5~4.5	
탄소(C)	0.6~3.0	일부 흑연 Graphite	수분 등 Moisture etc.	36~42	

Table I: The substance analysis results obtained from the EDS data, and reported in Ref. [1].

third sample, AM-III. Table I is the substance analysis results for the samples based on the EDS data that was included in the Cheonan report.[1] Here the element of interest is aluminum that is usually added to an explosive to maximize the effects of explosion.

Fig. 2 shows their x-ray data. Fig. 2 **a** and **b** show that the AM-I and AM-II

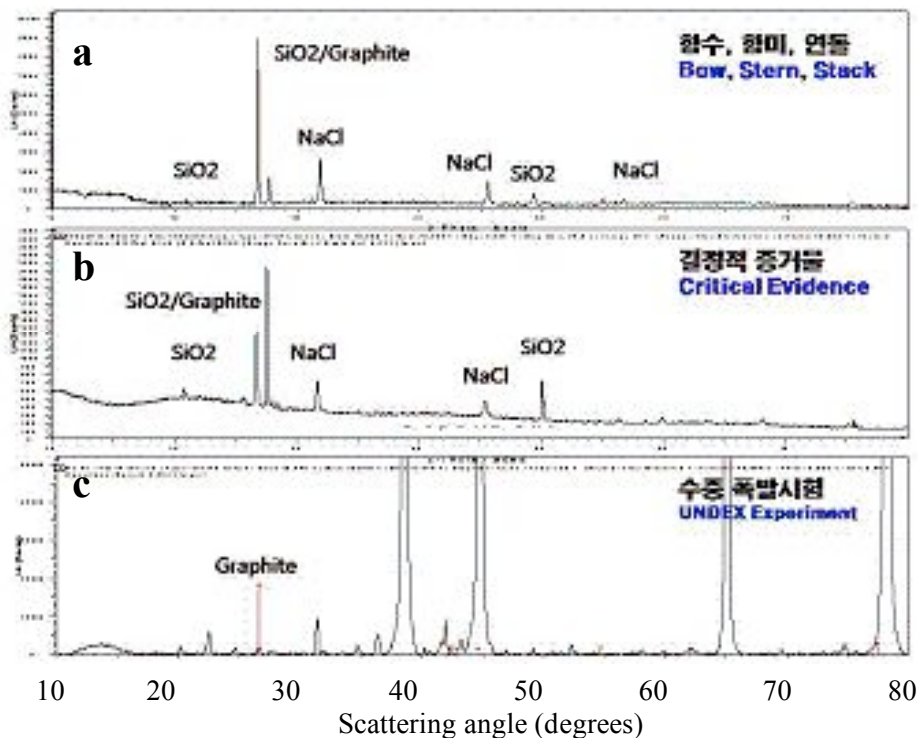


Fig. 2. The reported X-ray diffraction patterns obtained **a**, from AM-I, the absorbed material extracted from the “bow, stern, and stack” of the Cheon-An ship, **b**, from AM-II, “critical evidence”, extracted from the propeller of the torpedo, and **c**, from AM-III, “UNDEX Experiment”, extracted from the experiment after explosion. The horizontal and vertical axes represent the scattering angle and intensity of the scattered x-ray, respectively. The enlarged labels for the horizontal axis are added for clarity. This figure was taken from Ref. [1].

contain identical chemical compounds, showing the same Bragg peaks that are identified as the peaks from three compounds, SiO_2 , NaCl , and Graphite. Even though their EDS data showed significant fraction of Al, their x-ray data do not show any trace of aluminum or aluminum oxide. Korean CIV-MIL JIG interpreted these results as an evidence of aluminum and aluminum oxides becoming amorphous after the explosion – if true, it would be the first observation of the phenomena in the world. We will, however, show later that this is not true.

For now, let us turn to the x-ray data of the third sample AM-III taken from the test explosion. As shown in Fig. 2 c, the AM-III x-ray data is completely different from those of AM-I and AM-II: The AM-III data exhibits four strong and *sharp*

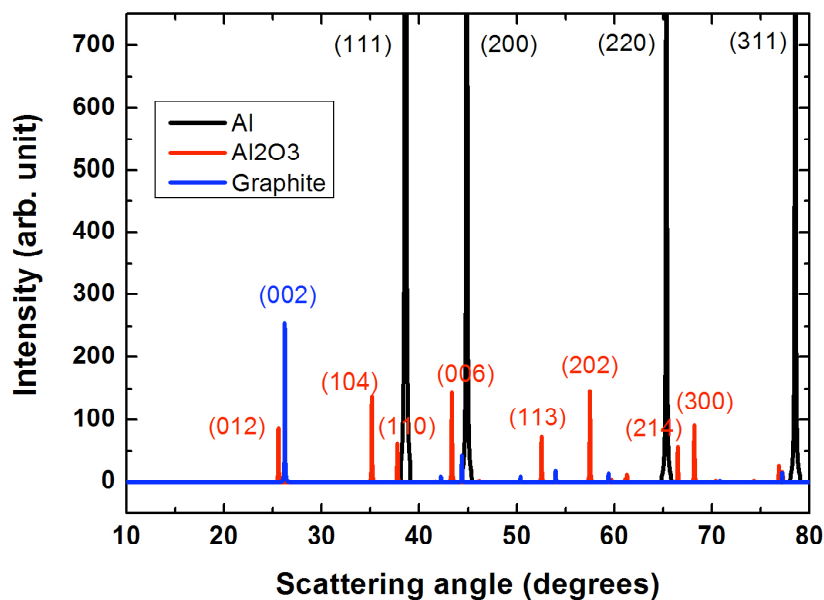


Fig. 3. Our simulation results for the x-ray diffraction patterns of crystallized Al (black), Al_2O_3 (red) and graphite (blue line). Their relative mass fractions were arbitrarily adjusted to mimic the experimental data shown in Fig. 2 c. The numbers represent the indices of the Bragg reflections.

peaks in the range of the scattering angle from 10 to 80 degrees: at about 38° , 45° , 65° and 78° . Our analysis tells us that the four peaks came from pure aluminum. They are the (111), (200), (220), and (311) nuclear Bragg peaks of pure aluminum (See the black line in Fig. 3). The sharpness of the peaks unambiguously tells us that the pure Al is well crystallized after

the explosion, which clearly contradicts the Cheon-An report's conclusion that Al must be amorphous after explosion. In addition, in Fig. 2 c one can see several weaker peaks that came from a small amount of Al_2O_3 . The Al_2O_3 peaks are also sharp, indicating that Al_2O_3 is also well-crystallized after the test explosion.

How can one explain this discrepancy? There are two possibilities. The first possibility is that the AM-III sample obtained from the test explosion is not related to explosive but it is mostly the Al powders that are scratched off from the Al top

plate of the metal box in which the test explosion was done. This can explain the neutron data. However, their claim, i.e., the same EDS data of the three samples indicate the AM-I and AM-II are explosive, is no longer valid. The second possibility is that the AM-III sample is mostly the explosive-related material, as claimed in the report.[1] If this is the case, its x-ray data tells that even after the explosion the crystalline aluminum rather than the amorphous aluminum should be dominant. Thus, similar sharp Al-peaks should have been observed in the x-ray data of the AM-I and AM-II. But they are not (see Fig. 2 **a** and **b**).

One may say that since the weight of the explosive in the test experiment is small, the temperature increase and the cooling rate of the ingredients of the explosive can be much smaller in comparison to the real torpedo case. But, that is not true. In their test experiment, both the weight of the water in the metal container and the weight of the explosive were scaled down in an equal ratio

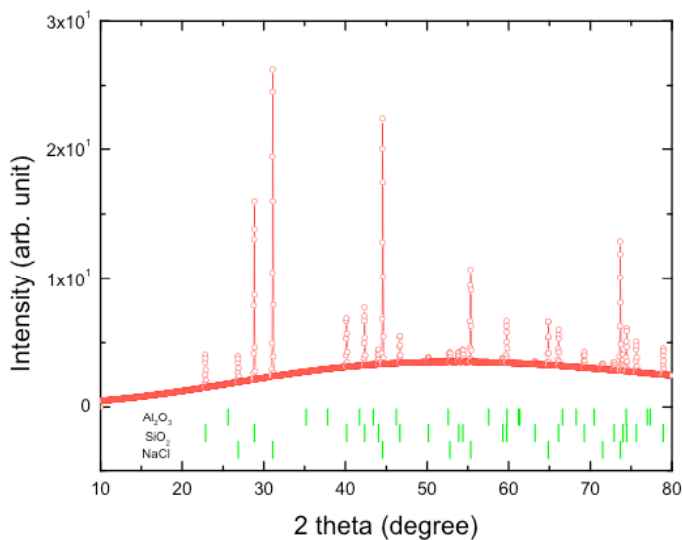


Fig. 4. Our simulation results of x-ray diffraction pattern for a mixture of amorphous Al_2O_3 (96%), and crystalline SiO_2 (2%), NaCl (2%). The sharp peaks are the Bragg peaks from SiO_2 and NaCl , while the broad peak centered at ~ 50 degrees comes from the amorphous Al_2O_3 .

compared to the case of a real torpedo, in order to produce the very similar conditions to the real torpedo explosion.[1] The heat generated by explosion is *proportional* to the weight of the explosive, and the temperature increase of the ingredients and water is *inversely proportional* to their weight for a given amount of heat. Thus, the effect of the scaling down cancelled out, and the test experiment should have yielded similar properties of the resulting materials after the explosion, which was the whole point of the test experiment.

Let us go back to the possibility of a torpedo explosion converting 100% Al into amorphous Al_2O_3 , the claim to explain the absence of Al or Al_2O_3 x-ray signals in the AM-I and AM-II samples. First of all, it is well-known that Al_2O_3 can be amorphous only in thin films [6], and it is highly unlikely to make the 100 % oxidized bulk Al_2O_3 . But let us say it happened by magic. The question is then whether or not the amorphous Al_2O_3 should have been detected in the x-ray diffraction. From the EDS data and their substance analysis, the weight amount

of S was determined to be $\sim 4\%$ of the total weight of each sample (see Table I). Since the EDS signals of Si and Na are much smaller than that of S, at least by a factor of 5 (see Fig. 1), it is safe to say that the maximum possible weight ratio of Si and Na in each sample was 1% . Using the program FullProf [7], we simulated x-ray diffraction pattern expected for a mixture of crystalline SiO_2 and NaCl, and amorphous Al_2O_3 with the weight ratios of SiO_2 :2%, NaCl:2%, Al_2O_3 :96%. An amorphous material would produce a broad peak rather than sharp Bragg peaks. The position of the broad peak will reflect the positions of the sharp Bragg peaks of crystalline Al_2O_3 . The breadth of the peak is inversely proportional to the length scale of the atom-atom correlations in the material. The existence of such a broad peak for amorphous materials such as metallic glasses is well documented (See Refs. [2] and [3]). For our simulation, to be conservative we assumed the correlation length to be the smallest Al-Al distance, 2.654 Å, in Al_2O_3 . Fig. 4 shows our simulation results. Clearly, the amorphous Al_2O_3 would have produced a broad peak centered at $\sim 50^\circ$, that should have been detected. But the signal was magically undetectable in their x-ray data.

In summary, the EDS and x-ray data of the “adsorbed materials” presented in the CheonAn report have several serious self-contradicting aspects and their interpretations have serious flaws, to say the least. Their conclusions based on the data are therefore groundless. Finding out how the tragic incident really occurred in the night of March 26, 2010 would demand a careful reexamination of all the information available by an objective international team of experts.

Methods

Electron-dispersive spectroscopy (EDS) probes electronic states of an atom.[4] Each atom has different electronic energy states, and as a result different atoms generate x-ray signals at different energies when the sample is hit by an incident beam of charged particles such as electrons. This technique can unambiguously identify what kind of “atoms” exists inside the sample. On the other hand, X-ray diffraction probes what kinds of chemical compounds the atoms form.[5] When x-rays are injected, the compound reflects the x-rays into a certain set of directions that are specific to the crystal structure of the compound. Thus, x-ray diffraction can be used to unambiguously determine the “chemical compounds” in a given sample. Our simulation of x-ray diffraction patterns was done using the program FullProf [7].

Acknowledgement

We thank Representative MunSoon Choi, and a few brave Korean people whose names I cannot reveal for their safety, for providing the information and for discussion.

References

- [1] The Cheon-An report by the Korean CIV-MIL JIG (Min-Goon Joint Investigation team) that was partially released very recently to the members of the Congressional Cheon-An committee. The office of Representative Choi, MunSoon, provided us the report.
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