Researching Influence of Climatic Environmental Parameters on Performance of Large Caliber Ammunition during Storage

Berko Zecevic[1], Nurin Zecevic[2], Jasmin Terzic[3], Miroslav Sain[4]

Abstract

Influences of environment on ammunition and weapon performance are the subject of continuous research to be able to estimate lifetime of ammunition and establishing quality control. Researching about causes of failure and cancellation of mechanism on some part of ammunition as warhead, cartridge with propellant, primer, fuses and pyrotechnics components are intensively continue to implement.

Temperature and humidity of environment are the main parameters that influence on performance of ammunition during storage. Available date about climatic environmental influence during storage of ammunition and detection of factors that influence on the lifetime of ammunition are relatively scant.

Measurements of temperature and relatively humidity are taken at three geographical locations with different atmospheric parameters on specific warehouses during all four seasons. Temperature and humidity changes are measured outside and inside of warehouse. At the same time, temperature and humidity changes are measured inside of ammunition box and inside of tight fiber container with ammunition. Measurement results are very interesting and require continuous measurements for a longer period. There is necessity to make a model for heat and mass transfer in a complex package of ammunition, which is consisted of inner and outer packaging.

Keywords: ammunition, lifetime, shelf-life, storage, temperature, humidity

1. INTRODUCTION

Due to the increased number of completed combat mission, ammunition shelf-life becomes very important question for countries in mild climate areas. Lifetime of ammunition is very often limited with propellant aging and condition of storage ammunition.

Ammunition shelf-life or propellants is consisted of two components [1]:

- Safety shelf-life and
- Functional or ballistic shelf-life.

[1] *Corresponding author: University of Sarajevo, Mechanical Engineering Faculty, Department of Defense Technologies, 71000, Sarajevo, Bosnia and Herzegovina, zecevic@mef.unsa.ba*

[2] *University of Sarajevo, Mechanical Engineering Faculty, 71000, Sarajevo, Bosnia and Herzegovina, svjetlanaz@mef.unsa.ba*

[3] *University of Sarajevo, Mechanical Engineering Faculty, Department of Defense Technologies, 71000, Sarajevo, Bosnia and Herzegovina, terzic@mef.unsa.ba*

[4] *University of Sarajevo, Mechanical Engineering Faculty, PhD student, 71000, Sarajevo, Bosnia and Herzegovina, miroslavsain@gmail.com*

Safety shelf-life of ammunition is often called chemically safe shelf-life and it is a period when the propellant is safely storage without any risk for environment. Safety shelf-life is limited with intensity of chemical reactions by aging, like degradation of nitrogen ester and reaction of these degradation products with stabilizer in the propellant. Functional life or ballistic shelf-life is a period when propellant or ammunition can be safely used and during which inner ballistic parameters are unchangeable. Main factors of propellant that limit functional life are decreased molecular weight of nitrocellulose, as a result of diffusion and incompatibility of the aging process. It is normal that ballistic shelf-life of ammunition usage is shorter than safety shelf-life ammunition usage. Shelf-life is interval during which propellant can be stored without danger, operated and used.

Influence of natural environment on ammunition and weapon performance are the subject of continuous study, with the aim to estimate shelf-life of ammunition and establish supervision and control of ammunition quality.

During ammunition storage, temperature fluctuations are very dangerous during day and night with the presence of high humidity. Effects of high temperatures can be physical, chemical effects or combined influence of these two effects. It is important to emphasis that during high temperature and high humidity, negative effects are more significant than when it is lower temperature [2].

To achieve optimal conditions for storage of explosive materials, it is desirable to keep temperature and relatively humidity within certain limits. Ideal conditions are that relative humidity at ammunition warehouse is between 50% and 60%, and temperature inside of warehouse is in interval from 5˚C to 25˚C [3]. Higher relative humidity can cause ammunition damage, and lower humidity can cause static electricity. Higher air temperature can intensify degradation reaction of certain components inside of explosive matters.

In the case when ammunition is longer exposed not only to increased temperature, also to solar radiation, it causes degradation of explosive charge in projectile, if temperature arise above 63˚C.There is possibility that explosion exude through screw joint of fuse and projectile body, and that represents extremely dangerous condition in the launching phase because of the possible projectile explosion in the barrel of weapon.

Pyrotechnic materials are heterogeneous mixture of different materials and very sensitive on higher temperatures during storage. Adhesives of these mixtures are very sensitive on high temperatures and melting, which can cause failure of these systems. Combination of increased temperature and humidity, significantly reduces shelf-life of pyrotechnic materials.

Materials like rubber and different types of plastic are rapidly aging with the increase of environmental temperature, especially if they are directly exposed to the sun and ultraviolet radiation. These materials then become hard and brittle, and rough handling or firing can cause failure of that subsystem.

Impact of humidity in the warehouse can be very complex and significantly depends on air temperature. Humidity at high temperature is significantly higher than at low temperatures:

- When moisture migrates in the chain combustion system, it can lead to the failure of overall system in the phase of launching.
- Single base propellant for guns is very sensitive on humidity impact.
- Direct contact of moisture with metal surfaces that are not enough surface protected causes corrosion (Figure 1 and Figure 2). Effect of corrosion increases in the case of explosive material degradation and reaction with the remains of acid. Humidity can influence on ammunition components and cause uncontrolled chemical reactions, very often with unwanted consequences.
- Because of moisture, ammunition can become unstable and very dangerous. Ammunition is usually stored in buildings that are partly covered with ground. Inside of warehouse is usually high humidity, resulting in occurrence of corrosion and rapid degradation of chemical compounds.
- Reducing relative humidity at warehouses, ammunition shelf-life can be extended.
- Moisture in the air causes presence of corrosion on steel surfaces. When relative humidity is below 45-50%, then steel objects can be stored without any problem. When relative humidity is above 60 %, then the process of corrosion begins on metal objects and if water vapor is present in the air, then the corrosion process is intense (Figure 3).
- Pyrotechnic materials that consist aluminum and magnesium powder, in contact with the moisture can cause oxidation of steel surfaces and difficulties in the process of ignition. Interaction of aluminum powder and increased humidity can cause presence of hydrogen inside of pyrotechnic composition and very serious safety problems.

Diurnal temperature cycling (day-night) can cause that dew point temperature is equal air temperature, and extraction of water from humid air. Extracted water from air migrates inside of ammunition packing or pervades through seals and joints in ammunition. Because of that, it is very important to design package and components of ammunition that ensure good sealing and waterproof. More complex type of ammunition as part of the package have also indicators of humidity level. Completing ammunition and package, or opening the package with ammunition during inspection and supervision should be done when the level of humidity is low and temperature of the air is also low.

Figure 1. Influence of surface corrosion on AP ammunition 76 mm 345B

Figure 2. Corrosion caused by moisture on pyrotechnical materials in ammunition [5]

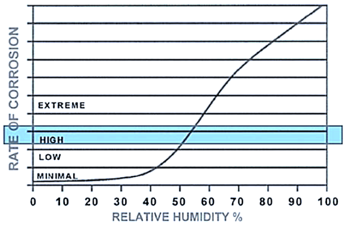

Figure 3. Typical Rate of Corrosion for Ferrous Metals [4]

Higher air temperature during storage of ammunition causes rapid aging of energetic material. Increasing temperature inside of warehouse for 10˚C will generally accelerate chemical reactions for 2 to 3 times [5]. If it is improperly packed, moisture can enter into energetic material and cause degradation by increased rate degradation. Contemporary studies about natural environmental influence on ammunition have shown that it is no longer enough to read temperature once per day, but continuous control of ammunition is necessary (operation in Iraq, Afghanistan, Djibouti etc.). Significant deviations of actual temperature with time were observed, compared to the measurement of a long term mean temperature by time for given warehouse location [6]. Besides that, very important factor is a measurement of temperature and humidity within each package of ammunition. This results with precise data necessary for estimation of remaining ammunition shelf-life.

Researching that are made in Iraq [7] with the aim to determine natural environment impact on shelf-life of ammunition pyrotechnic components (flare), influence of ammunition transport and realistic conditions of storage, made it possible to determine critical data for storage temperature and humidity. Researching comparative functional performance of flares that were exposed to the influence of extreme natural environmental conditions, compared to the flares that were not exposed to these conditions, has shown significant differences.

Increase of humidity and temperature, causes growth of mold on certain ammunition components. With the decrease of relative humidity, process of creating mold can be stopped and in the future growth of mold can be stopped completely.

Large number of explosive materials is sensitive on humidity and because of that, control of humidity has to be done in storage of ammunition and bulk explosive materials. Many components of complicated armed system before integration in projectiles are kept in special containers, in which are certain amount of adsorption substances, type silica, that have ability to absorb humidity. But, ammunition is a complex system and at the same time under the influence of increased temperature and humidity, several different processes are happening. All these processes directly influence on shelf-life of ammunition.

Last 25 years of intensive engagement of armed forces USA and NATO countries in Iraq and Afghanistan are followed by intensive transport of ammunition and its storage under temperatures that have achieved in desert about 60˚C or 70˚C, causing rapid degradation of energy materials in ammunition [8].

Shelf-life of such ammunition is not so long as it was specified by manufacturer. Now, question of ammunition maintain has become essential. Need for periodical control and inspection of ammunition is not only from the point of security, reliability and functional performance, but also from the point of operational status during the war of low intensity.

Chemical effects at increased temperatures are reflected on composition of explosive materials and materials as rubber and plastic. In explosive material, chemical effects due to the increased temperature influence are reflecting in degradation and decreasing ballistic performance or causing chemical degradation of materials and gas occurrence that can cause cracks in propellant charge. According to American concept for estimation shelf-life of propellant for gun, degradation degree of guns propellant during longer exposure to increased temperature, is twice higher per every increase of ammunition temperature, for every 10˚C rise in temperature above 30˚C (Figure 4) [2].

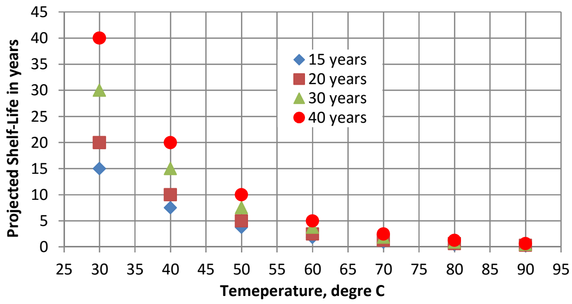

Figure 4. Projected shelf-life gun propellants with increasing temperature above 30˚C (American criteria)

Depending on chemical composition and shape, most of the gun propellants have shelf-life from 15 to 25 years on 30˚C.In mid climatic conditions, its shelf-life can be longer, but during storage under increased temperatures, it is necessary to do earlier control and propellant testing. When designed shelf-life expires, propellants must be tested to establish the remaining amount of stabilizer and to estimate if shelf-life of propellant can be extended.

Decreasing stabilizer content in propellant in the case of delivering external heat or long-lasting process of fuel decomposition can cause self-ignition of propellant in ammunition during storage and explosion of warehouse. It is undesired not only from the safety point, but also from economic, operative and logistic reasons [5].

During ammunition storage, NOx separates from propellant and binds with moisture in the air. A result of that reaction is nitric acid. Material used for propellant charge bags, at propellant charge ammunition can cause deterioration of textile quality (Figure 6) and threaten ammunition function (safety and functional reliability) [9].

Physical effects at increased temperatures cause stress state between certain components at explosive materials. Different materials have different expansion rate and under sudden change of temperature, as a result there are very high stress states on contact surfaces (Figure 5). During large diurnal temperature cycles, it can cause early failure of seals.

It is necessary to continually measure temperature and relative humidity in warehouse. Humidity control inside of container of more complex system is done often in accordance with instructions for certain weapon systems, usually per week. It is necessary to know that with increase of temperature for every 10˚C, increases amount of water in the air for double, but relative humidity decreases by half. When temperature decrease for every 10˚C, relative humidity increases for 50%, until it reaches 100 %. After that, further decrease of temperature causes extraction of water in the air.

Degradation of ammunition does not happen overnight, but when it reaches certain years of age. When ammunition reaches more than 20 years, its reliability rapidly degrades. It can be assumed that 7-8% of ammunition will be lost annually, after reaching age limit of 20 years [10].

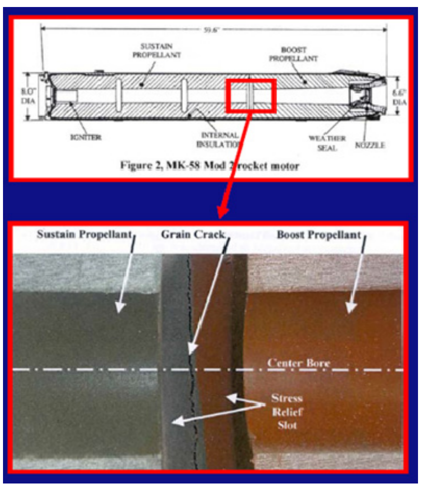

Figure 5. Presence of cracks in rocket charge propellant because of inner stress (Source: paper P. Huisveld, AVT-RTO-089, 2002 Aalborg) [12]

Figure 6. Influence of moisture on bag for propellant charge ammunition 155mm [8]

According to Indian army sources, manufacturer of fuse, in its technical specification, notifies that „minimum shelf-life of fuse for ammunition 155 mm would be 10 years, without deterioration, when it is stored under controlled conditions at temperature 21± 2°C and relative humidity of air that is not higher than 60%, but in the case of storing on open space, minimum shelf-life is six months“ [11].

2. RESEARCHING

Researching about temperature and humidity changes are done in ammunition storage on three location that are geographical and climatic very different in period of time that includes four seasons. The aim of research process is to identify natural environmental parameters that can threaten safety and decrease shelf-life of ammunition [13].

Data is continuously collected by sensors for temperature and humidity measurement on all three locations, or on five objects. Three objects for ammunition storage are Earth Covered Magazine-ECM and other two objects are Above Ground Magazine-AGM. On every location, sensor for temperature and humidity measurement was mounted, resistant to external conditions. Inside of every object, one device with sensors for temperature and humidity measurement was mounted, characterized as safe to work with it in storage of ammunition and explosives. One sensor was mounted inside of wooden box with ammunition that was in fiber container, and second sensor was mounted inside of fiber container (impregnated, waterproof, card boarded) together with ammunition to control state in which is ammunition.

Measurement of temperature and relative humidity at warehouses is done by data logger system Tinytag Plus TGIS-1580 Intrinsically Safe Dual Channel Temperature/Relative Humidity (-40 to +85°C/0 to 100% RH), that allows continuous control of temperature and relative humidity inside of dangerous zones for storage.

2.1. Climatic environmental parameters at ammunition storage locations

Researching about Climatic environmental parameters are carried on locations A, B and C, on different geographical positions. Ammunition storage A is located along a valley surrounded by mountains and along the creek, running through valley. Two magazines are being considered, object ECM-A and object AGM-A. Ammunition storage on location B are located on one plateau, where object ECM-B-1 is located on small basin, and object ECM-B-2 is located in the level with plateau. Magazine AGM-C on location C is located on hill-side, oriented toward the coast.

Measurement results show that there are no significant differences in climatic environmental parameters on ammunition storage locations A and B, but there is perceptible difference in parameters on location C comparing with two other locations (Figure 7 and Figure 8).

On all three ammunition storage locations, maximum environmental temperature during particular period of measuring time does not across 35˚C. Results of relative humidity on all three ammunition storage locations are disturbing, specially on locations A and B. Generally, most of the time during year, ambient relative humidity at ammunition storage locations A, B and C are in the range of 60% to 100%.

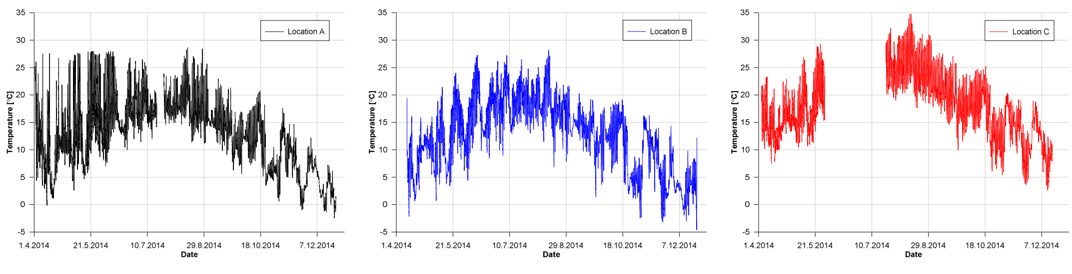

Figure 7. Temperature change at ammunition storage locations A, B and C

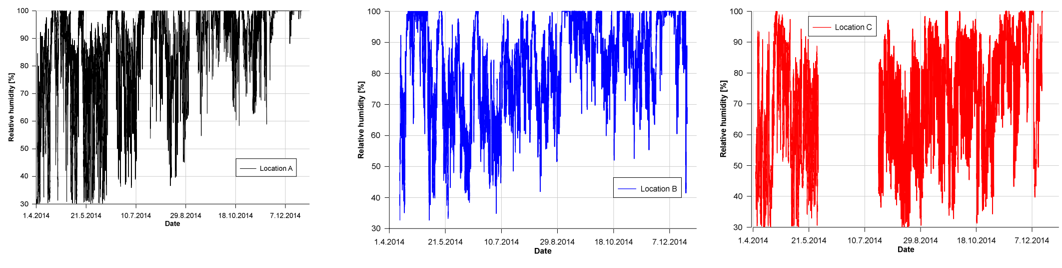

Figure 8. Relative humidity change at ammunition storage locations A, B i C

2.2. Influence of Climatic environmental parameters on the inside of ammunition magazine

Because all five objects that are located on three locations are being considered, where three objects are type ECM and two objects type AGM, there are large differences in the structure between ammunition magazines ECM and AGM. Because of that, environmental influence on temperature and relative humidity parameters inside of the objects will be particularly considered for every type of the ammunition magazine.

Analysis of measurement results for temperature inside of the ammunition magazines ECM-A, ECM-B-1 and ECM-B-2 shows almost identical temperature changes of storage in measurement period. Temperature inside of magazine during considered period was moving from 5˚C do 18˚C, which is extremely suitable for a long-term ammunition storage (Figure 9 and Figure 10).

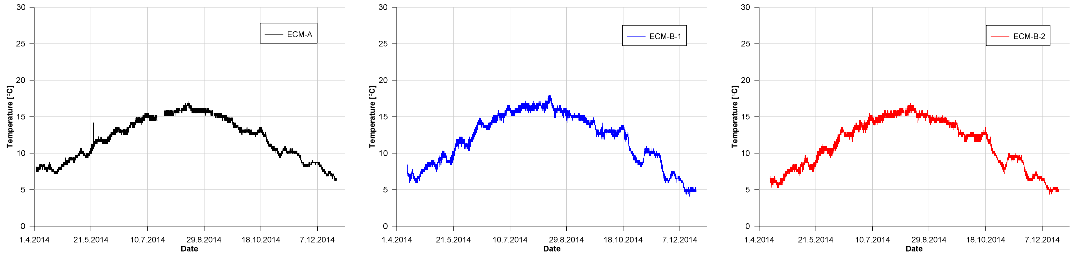

Figure 9. Temperature change inside of the object ECM on location A and B

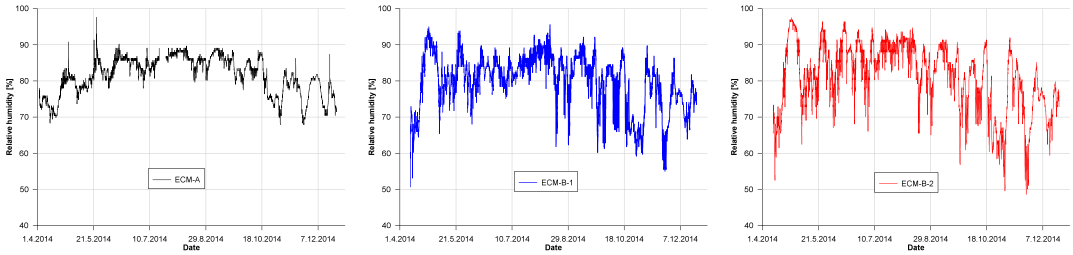

Figure 10. Relative humidity change inside of the object ECM on location A and B

Anaylsis of measurement results for relative humidity inside of three magazines type ECM on locations A and B, shows certain mutual deviations. Average relative humidity inside of these three objects type ECM was about 80%. In the object ECM-A, range of relative humidity change inside of the ammunition magazine varied between 70% to 90%, with relatively small amplitudes of relative humidity change within a short measurement period. Inside of the objects ECM-B-1 and ECM-B-2, range of relative humidity change was between 50% to 95%, with very large amplitudes of relative humidity change within a short measurement period, which clearly points on problems with natural ventilation system of the objects.

Analysis of measurement results for the internal temperature of magazines AGM-A and AGM-C, shows perceptible differences in temperature changes of storage in particular measurement period, which is objectively result of large differences of outside temperature on considered ammunition storage locations (Figure 11 and Figure 12).

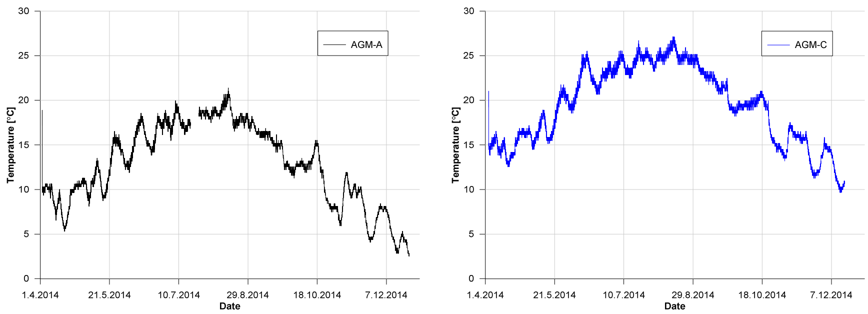

Figure 11. Temperature change inside of the object type AGM on location A and C

Temperature range inside of magazine AGM-A in particular measurement period was from 3˚C do 22˚C, while the temperature range inside of magazine AGM-A in particular measurement period was from 10˚C do 27˚C, which is suitable for a long-term ammunition storage.

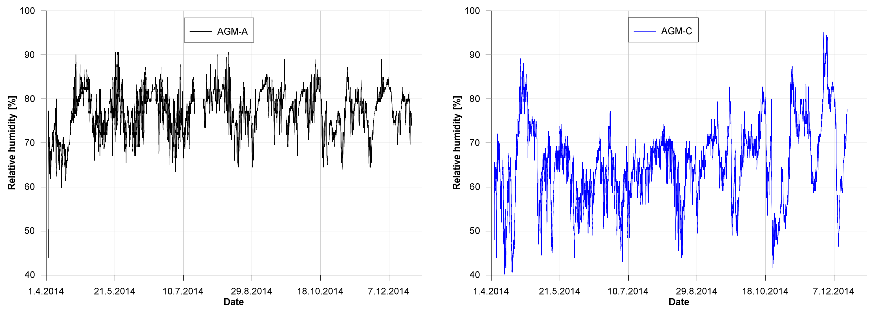

Figure 12. Relative humidity change inside of the object type AGM on locations A and C

Analysis of measurement results for relative humidity inside of these two magazines type AGM on locations A and C, shows mutual significant deviations. Average relative humidity inside of the object AGM-A was about 77%, inside of the object AGM-C was about 65 %.

Inside of the object AGM-A, range of relative humidity change inside of the magazine varied between 65% and 90%, with relatively small amplitudes of relative humidity change within shorter measurement period. Inside of the object AGM-C, range of relative humidity change was between 45% to 95%, but with very large amplitudes of relative humidity changes within shorter measurement period, which clearly points on problems with natural ventilation system of the objects.

2.3. Influence of Climatic environmental parameters on the inside of ammunition packaging

Modern ammunition packaging is consisted of internal and external packing (Figure 13). External packing can be wooden box or metal box, which has primarily task to prevent ammunition from physical damage during transport, operation and storage. Internal packing needs to be hermetic and to protect ammunition from impact of significant temperature and humidity changes. It is usually fiber container in which is ammunition placed, and recently plastic containers are more often used. Unfortunately, significant amount of ammunition of eastern concept does not consist internal packing (Figure 14) and ammunition is directly exposed to the influence of climatic changes inside of magazine.

Figure 13. Wooden box with inner fiber container (Western concept)

Figure 14. Wooden box with ammunition without internal packing (Eastern concept)

Environmental measurement parameters inside of ammunition packaging were compared, especially for the objects type ECM, or AGM. Objects ECM-A i ECM-B are identical by design and performance, but minor differences were noticed in registered values of maximum temperatures in wooden box, but registered values of minimum temperatures in wooden box that were placed in objects ECM-B-1 and ECM-B-2 are lower for about 5˚C. Besides that, temperature amplitudes inside of these boxes are higher than temperature amplitudes inside of considered magazines (Figure 15).

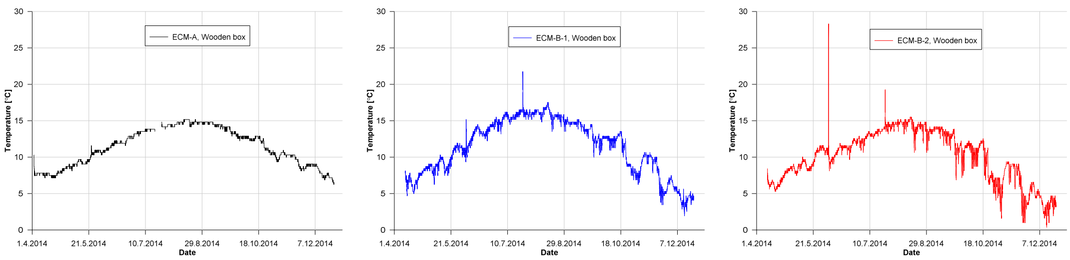

Figure 15. Temperature change inside of wooden box in the objects type ECM on locations A and B

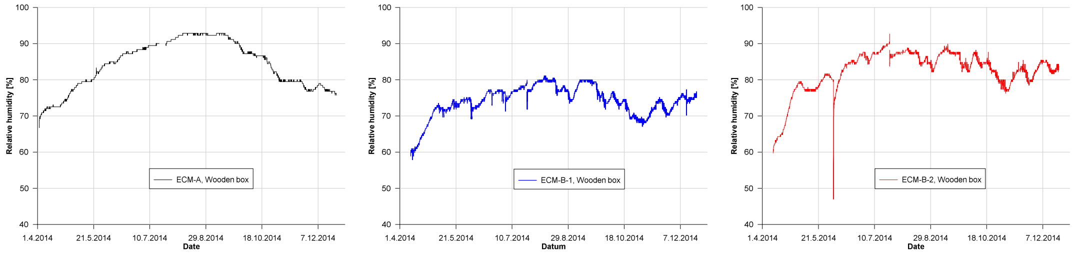

Figure 16. Relative humidity change inside of wooden box in the objects type ECM on locations A and B

Relative humidity in wooden boxes in all three ECM objects is in the range between 60% to 90% (Figure 16), which represents a great danger for ammunition that does not have inner packing, because of the conditions that are suitable for corrosion of metals.

Registered changes in temperature values inside of fiber containers are almost identical to temperature changes in wooden boxes in all three ECM objects for particular measurement period. The maximum registered temperature inside of fiber container was 17˚C (Figure 17), which is extremely suitable from the point of explosive materials stability inside of ammunition.

Relative humidity values in fiber containers in all three ECM objects is about 70 % for the object ECM-A, or 75% for objects ECM-B (Figure 18), which represents a great danger for corrosion of metal. A relative humidity change in fiber containers for a total measurement period is within interval of 5%. That data is very important, because it requires that the process of ammunition mounting into fiber container is carried out in controlled atmosphere, when ambient temperature should not be lower than 20˚C, and relative humidity should be in the range between 40% to 50%. When fiber container with ammunition is hermetic, the current parameters of atmosphere are frozen for a longer period.

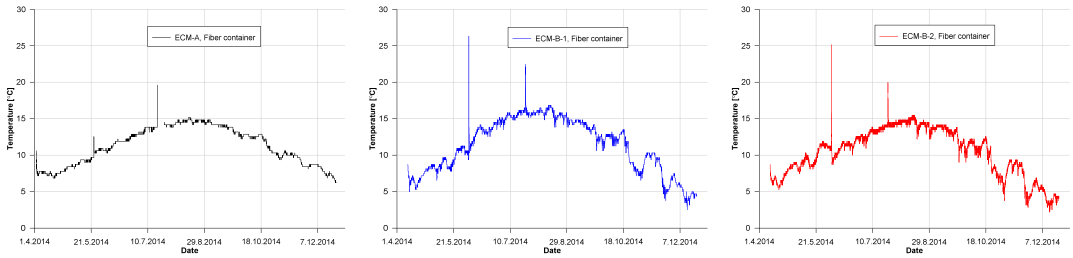

Figure 17. Temperature changes inside of fiber container in objects type ECM on locations A and B

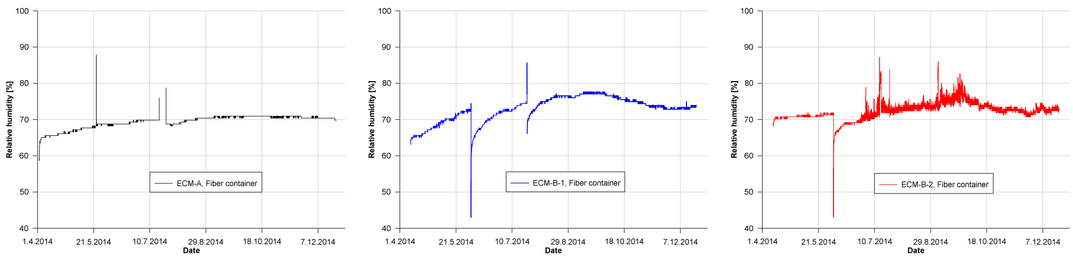

Figure 18. Relative humidity change inside of fiber container in objects type ECM on location A and B

During analysis of atmospheric parameters in boxes that are placed above ground of magazine – AGM, it is perceived that character of air temperature changes is similar to the temperature change at magazine.

Temperature in the box in object AGM-A is higher for about 5˚C comparing with the temperature inside of the box in object ECM-A, that is placed at the same location of ammunition storage. Temperature in the wooden box in object AGM-C is higher for about 5˚C comparing with the temperature inside of the wooden box in the object AGM-A (Figure 19), which is result also of higher ambient temperature at the ammunition storage location C.

Relative humidity changes inside of wooden box in objects type AGM at locations A and C are not in the accordance with temperature inside of wooden box, because of influence of natural ventilation and characteristics of production wooden boxes (gaps between wooden boards).

Registered changes of temperature values inside of fiber containers are almost identical to the temperature changes in wooden boxes in both AGM objects for particular measurement period.

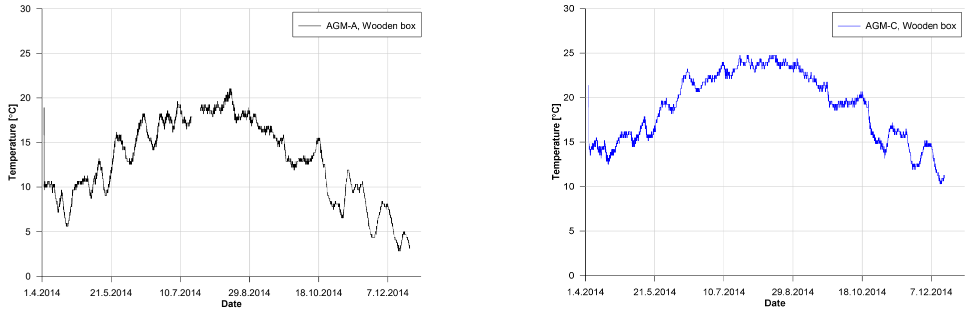

Figure 19. Temperature change inside of wooden box in objects type AGM on locations A and C

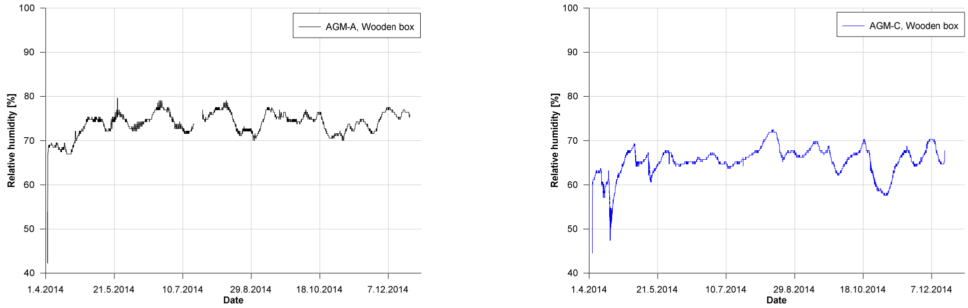

Figure 20. Relative humidity change inside of wooden box in objects type AGM, on locations A and C

The maximum registered temperature inside of fiber container, placed in object AGM-A was 20˚C, and maximum temperature of 25˚C was measured in the object AGM-C, which is suitable from the point of explosives stability inside of ammunition. Total range of temperature changes during a total measurement period was about 15˚C (Figure 21).

Relative humidity values in fiber container in AGM-A object was about 75%, or 65% for AGM-C object, which presents a great danger for ammunition because of metal corrosion. Changes in relative humidity values in fiber containers for a total measurement period are in the range within interval of 10% for AGM-A, or about 15% for AGM-C (Figure 22).

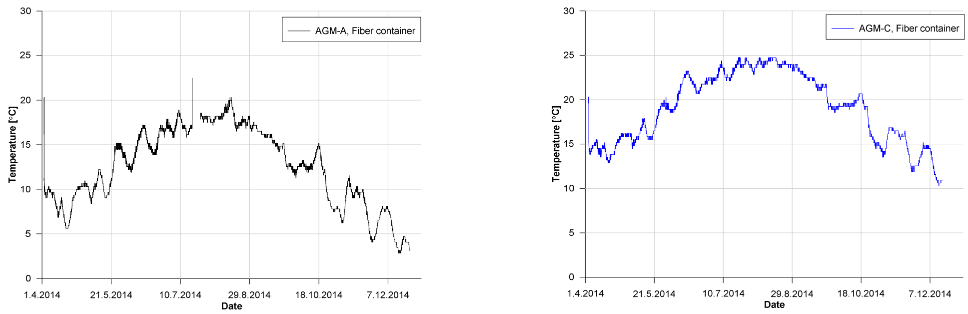

Figure 21. Temperature change inside of fiber container in objects AGM, locations A and C

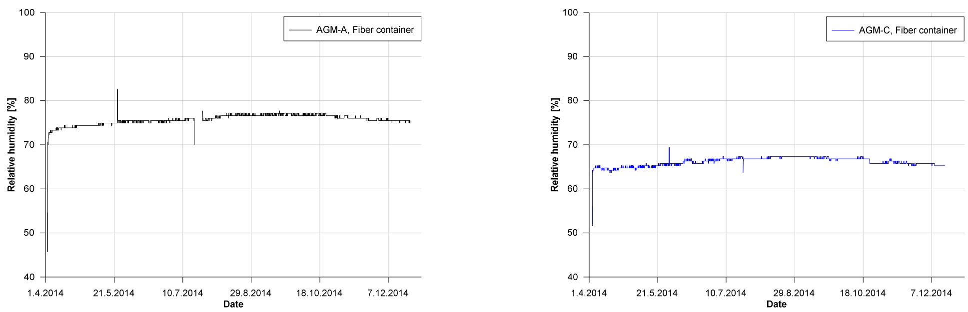

Figure 22. Relative humidity changes inside of fiber container in objects type AGM, location A and C

3. CONCLUSION

Temperature and humidity changes were monitored at ammunition storage on three locations, that are geographically and climate completely different in the period of four seasons.

Three objects for ammunition storage were type ECM, and two objects were type AGM.

On every location, sensor for temperature and humidity measurement was mounted, resistant to external conditions. Inside of every object, one device with sensors for temperature and humidity measurement was mounted, characterized as safe to work with it in storage for ammunition and explosives.

The ambient temperature at all three locations during summer months can be significantly above 30˚C, and sometimes it reaches temperature close to 40˚C.

The maximum temperature inside of the object type ECM was about 15˚C, and inside of the object AGM it reached values of 20˚C (AGM-A), or 25˚C (AGM-C).

From the point of temperature inside of magazines, conditions that can raise rapid degradation of weaker explosives (propellant, black powder and pyrotechnics) did not occur.

Unfortunately, relative humidity on all locations often reached the level of 100% relative humidity.

Average relative humidity inside of magazines type ECM was about 80%, and inside of the object type AGM was in the range between 65% to 77%.

Relative humidity inside of wooden box varied between 60% and 90%, and character of changes was very often similar to the changes of relative humidity inside of magazines.

Relative humidity inside of fiber container (card boarded, impregnated with bitumen layer outside) varied within interval between 65% and 75%.

This high relative humidity inside of wooden box and fiber container represents a great danger for intensifying corrosion process of metal ammunition surfaces, and especially if there is possibility for negative impact on pyrotechnic elements (traces, fuse, ignition charge etc) and on electronic components like guided ammunitions etc.

During ammunition mounting into fiber container or during inspection or ammunition remount, this process needs to be carried out in controlled atmosphere, when ambient temperature should be lower than 20˚C , and relative humidity should be in the range from 40% to 50%. When fiber package with ammunition is hermetic, then current parameters of atmosphere are frozen for a longer period.

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