5.3 The effects of air pollution on materials and cultural properties

5.3.1 Introduction

The effects of air pollution are not only on peoples' health and living things such as plants, but also extend to man-made items such as materials like metals and cultural properties. To recognize and investigate the effects of air pollution on materials and cultural properties is to evaluate the economic loss from the air pollution and at the same time improve the safe maintenance of public assets, starting with municipal facilities. Furthermore, we must identify the long term effect on cultural properties, which are assets of all mankind but cannot have an economic value placed on them, and improve measures to preserve them. Because of this, each region and each individual country must investigate and identify their effects on the materials and cultural properties, and it is very important to apply these measures .

5.3.2 The effects of air pollution relating to raw materials

The degree of the effect of air pollutants materials on materials is shown on Table 5.3.1 [1]. Hydrogen sulfide greatly affects silver and copper, and sulfuric acid has a large effect on iron, steel and stone. Also, ozone has a large effect on high molecule organic substances. In this way, depending on the material and its type, the degree of the effect of air pollutants will be different. Accordingly, knowing the characteristics of a region's air pollution is the foundation for knowing what materials will be affected to what degree by that region's air pollution.

Table 5.3.1 Damage sensitivity of materials to air pollutants

Materials / Pollutants	Silver	Copper	Bronze	Brass	Iron	Steel	Tin	Lead	Pewter	Nickel	Aluminum	Stone	Polymers	Lacquer	Paper	Photographs	Textile
Water	L	L	L	L	H	H	L	L		N	L	L	N	N	H	L	N
Carbon dioxide	L	L	L		M	M		M		L							
Ammonia	M	M	L	L	M	M	L	L	N	N	L						
Nitrogen oxides	N								M	M	M	L			L	M	
Hydrogyn sulfide	H	H	M	L	N	M	N	L	H	N	L			L		M	
Carbonyl sulfide	H	H															
Sulfur oxides	L	L	L	L	H	H	N	L	H	M	L	H		M	M	M	M
Hydrogen chloride	L	L	L	L	H	H	L	L		L	L	L					
Formaldehyde		L			L	N					N						
Organic acid	N	M	M	L	H	L	L	H								L	
Ozone	M	M								M		M	H	M		L	L
Hydrogen peroxide					L						L					L	

H = High, M = Medium, L = Low, N = None, Blank = No data

The results of the Land Steel Preservation Research Council's Japan-wide investigation of SO_2, which was a large air pollution problem from the late 1950's until the early 1970's, are shown in Fig.5.3.1 [2]. The rate of steel corrosion in Kawasaki, an area with very heavy air pollution, was especially high, approximately ten times that of inland Takayama. By looking at this data we can see how much air pollution accelerates corrosion on materials.

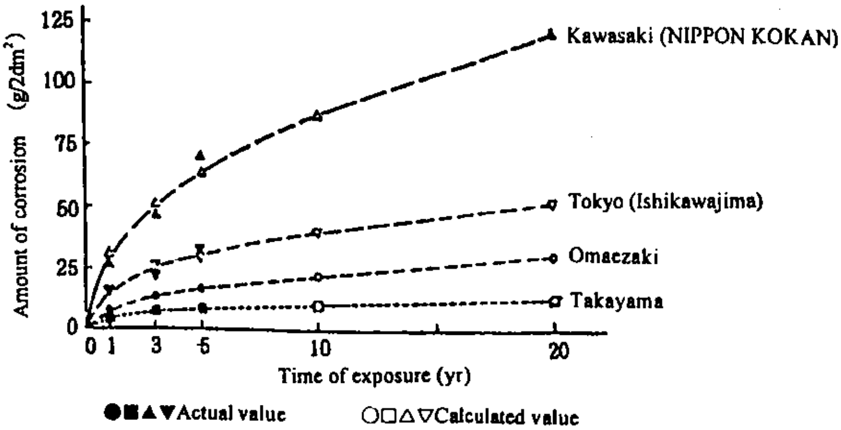

Fig.5.3.1 Amount of corrosion by calculated price of *kildo* metal

Using the example of a study of the relationship between air pollution and copper corrosion, the results of an investigation of the appearance of patina on copper outdoors in the eastern United States [3] are shown in Fig.5.3.2. We can confirm from Fig.5.3.2 that as air pollution progresses copper corrosion accelerates.

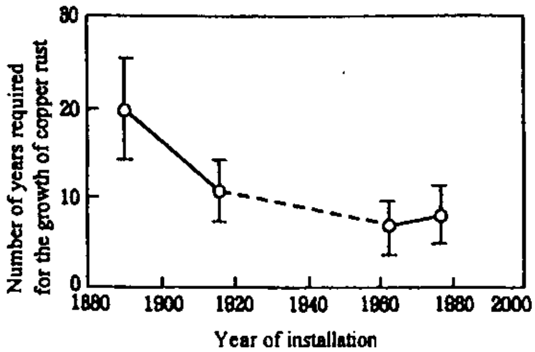

Fig.5.3.2 Number of years required for the growth of copper rust on copper surfaces installed each year in the eastern United States

Conversely, there is also the example of ranking the degree of pollution by the speed of corrosion on materials. The ranking by ISO material categories is shown in Table 5.3.2~5.3.4 [4]. Table 5.3.2 gives the categories of the major environmental factors which affect corrosion. Table 5.3.3 shows the speed of corrosion for different materials, but if the corrosiveness categories are all raked the same, the speed of corrosion on steel is the highest, followed by zinc and copper, and aluminum is the lowest. The current corrosion rate of steel throughout Japan is in the lowest corrosion category. Table 5.3.4 shows the relationship between environmental factors and speed of corrosion by category of material. For instance, we can understand that aluminum has a rather high corrosion speed as S_3.

Table 5.3.2 Categorization of principal environmental factors

Time of wetness		SO_2 amount applied			Amount of sea salt particles	
No.	h/y	No.	mg/(m²·d)	μ g/m³	No.	Cl⁻·mg/(m²·d)
τ_1	≦ 10	P_0	≦ 10	≦ 12	S_0	≦ 3 (5)
τ_2	> 10～250	P_1	>10～35	>12～40	S_1	> 3～60 (99)
τ_3	> 250～2,500	P_2	>35～80	>40～90	S_2	>60～300 (495)
τ_4	>2,500～5,500	P_3	>80～200	>90～250	S_3	>300～1,500 (2473)
τ_5	>5,500					

Note: Numbers in parentheses are NaCl·mg/m²·d

Table 5.3.3 Atmospheric exposure, First year rate of corrosion (r_{eoor})

Category number of corrosiveness	Rate of corrosion of metal (r_{eoor})				
	Unit	Carbon steel	Zn	Cu	Al
C_1	g/(m²·y)	≦ 10	≦0.7	≦0.9	Negligible
	μ m/y	≦ 1.3	≦0.1	≦0.1	–
C_2	g/(m²·y)	> 10～ 200	>0.7～ 5	>0.9～ 5	≦0.6
	μ m/y	> 1.3～ 25	>0.1～0.7	>0.1～0.6	–
C_3	g/(m²·y)	>200～ 400	> 5～ 15	> 5～ 12	>0.6～2
	μ m/y	> 25～ 50	>0.7～2.1	>0.6～1.3	–
C_4	g/(m²·y)	>400～ 650	>15～ 30	>12～ 25	> 2～5
	μ m/y	> 50～ 80	>2.1～4.2	>1.3～2.8	–
C_5	g/(m²·y)	>650～1,500	>30～60	>25～ 50	>5～10
	μ m/y	> 80～ 200	>4.2～8.4	>2.8～5.6	–

Table 5.3.4 Chart of categories of environmental corrosiveness by level of environmental factors

Metal		Carbon steel			Zn and Cu			Al		
Factor level		P_0-P_1	P_2	P_3	P_0-P_1	P_2	P_3	P_0-P_1	P_2	P_3
τ_1	S_0-S_1	C_1	C_1	C_1 or C_2	C_1	C_1	C_1	C_1	C_1	C_1
	S_2	C_1	C_1	C_1 or C_2	C_1	C_1	C_1 or C_2	C_2	C_2	C_2 or C_3
	S_3	C_1 or C_2	C_1 or C_2	C_2	C_1	C_1 or C_2	C_2	C_2	C_2 or C_3	C_3
τ_2	S_0-S_1	C_1	C_1 or C_2	C_2	C_1	C_1 or C_2	C_2	C_1	C_1 or C_2	C_3 or C_4
	S_2	C_2	C_2 or C_3	C_3	C_1 or C_2	C_2	C_3	C_2 or C_3	C_3 or C_4	C_4
	S_3	C_3 or C_4	C_3 or C_4	C_4	C_3	C_3	C_3 or C_4	C_4	C_4	C_4
τ_3	S_0-S_1	C_2 or C_3	C_3 or C_4	C_4	C_3	C_3	C_3	C_3	C_3	C_3 or C_4
	S_2	C_3 or C_4	C_4 or C_5	C_3 or C_4	C_3	C_3 or C_4	C_3 or C_4	C_3 or C_4	C_4	C_4 or C_5
	S_3	C_4	C_4 or C_5	C_5	C_3 or C_4	C_4	C_4	C_4	C_4 or C_5	C_5
τ_4	S_0-S_1	C_3	C_4	C_5	C_3	C_3 or C_4	C_4 or C_5	C_3	C_3 or C_4	C_4 or C_5
	S_2	C_4	C_4	C_5	C_4	C_4	C_5	C_3 or C_4	C_4	C_5
	S_3	C_5	C_5	C_5	C_5	C_5	C_5	C_5	C_5	C_5
τ_5	S_0-S_1	C_3 or C_4	C_5	C_3 or C_4	C_4 or C_5	C_5	C_4	C_4 or C_5	C_5	
	S_2	C_5	C_5	C_5	C_5	C_5	C_5	C_5	C_5	C_5
	S_3	C_5	C_5	C_5	C_5	C_5	C_5	C_5	C_5	C_5

5.3.3 Mechanisms for the effects of atmospheric pollution

The Schikorr formula [5] measures the chemical effect of SO_2 contribution to steel erosion and is a representative example of how air pollution contributes to the breaking down of materials. The following is example (1) of the Schikorr formula.

$$Fe + SO_2 + O_2 = FeSO_4$$
$$4\,FeSO_4 + O_2 + 6\,H_2O = 4\,FeOOH + 4\,H_2SO_4 \qquad \cdots\cdots (1)$$
$$4\,H_2SO_4 + 4\,Fe + 2\,O_2 = 4\,FeSO_4 + 4\,H_2O$$

This structure is called auto-catalytic, the reaction repeatedly produces FeOOH and promotes corrosion.

With marble, acid substances in the atmosphere promote deterioration by the following process. Atmospheric SO_2 and NO_2 oxidized in the atmosphere and become SO_4^{2-} and NO_3^- which makes rain become acidic causing acid rain. Acid rain acts on marble as shown in Eq. (2) and promotes deterioration.

$$CaCO_3 + 2\,H^+ \rightarrow Ca^{2+} + 2\,HCO_3^-$$
$$CaCO_3 + H_2SO_4 + H_2O \rightarrow CaSO_4 \cdot 2\,H_2O + CO_2 \uparrow \qquad \cdots\cdots (2)$$
$$CaCO_3 + 2\,HNO_3 \rightarrow Ca(NO_3)_2 + CO_2 \uparrow$$

Also, air pollution promotes the deterioration of other metallic materials.

5.3.4 Conclusion

It is difficult to measure air pollution's effect on cultural properties and materials, and the method must include a wide variety of investigations, making it difficult to standardize, but if the conditions necessary to standardize investigations are clarified, it is important to investigate utilizing the composite examination results to create measures addressing air pollution.