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Original Article

Multiplicative KG-Sombor Indices of Some Networks

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Abstract - *In this paper, we introduce the multiplicative KG Sombor index, multiplicative modified KG Sombor index of a graph. We compute these multiplicative KG Sombor indices for some chemical structures such as chain silicate, silicate, hexagonal and oxide networks.*

Keywords - *Multiplicative KG Sombor index, Multiplicative modified KG Sombor index, Chemical structures.*

Mathematics Subject Classification - *05C05, 05C12, 05C35.*

1. Introduction

Let G be a finite, simple, connected graph with vertex set $V(G)$ and edge set $E(G)$. The degree $d_G(u)$ of a vertex u is the number of edges incident to u. If e= uv is an edge of G, then the vertex u and edge e are incident and it is denoted by ue. Let $d_G(e)$ denote the degree of an edge e in G, which is defined as $d_G(e) = d_G(u) + d_G(v) - 2$ with $e = uv$. We refer the book [1], for undefined notations and terminologies.

The first and second Banhatti indices of a graph G were introduced by Kulli in [2], and they are defined as

$$B_1(G) = \sum_{ue}[d_G(u) + d_G(e)], \qquad B_2(G) = \sum_{ue} d_G(u)d_G(e)$$

where ue means that the vertex u and edge e are incident in G.

Recently, some Banhatti indices were studied in [3, 4, 5, 6].

The KG Sombor index was introduced by Kulli et al. in [7], defined it as

$$KG(G) = \sum_{ue} \sqrt{d_G(u)^2 + d_G(e)^2}.$$

Recently, some Sombor indices were studied in [8, 9, 10, 11,12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28].

In [29], Kulli introduced the modified KG Sombor index of a graph G and it is defined as

$$mKG(G) = \sum_{ue} \frac{1}{\sqrt{d_G(u)^2 + d_G(e)^2}}.$$

Inspired by work on KG Sombor indices, we introduce the multiplicative KG Sombor index, multiplicative modified KG Sombor index of a graph as follows:

The multiplicative KG Sombor index of a graph G is defined as

$$KGII(G) = \prod_{ue} \sqrt{d_G(u)^2 + d_G(e)^2}.$$

We can express the multiplicative KG Sombor index as

$$KGII(G) = \prod_{uv \in E(G)} \left[\sqrt{d_G(u)^2 + (d_G(u) + d_G(v) - 2)^2} + \sqrt{d_G(v)^2 + (d_G(u) + d_G(v) - 2)^2}\right].$$

The multiplicative modified KG Sombor index of a graph G is defined as

$$mKGII(G) = \prod_{ue} \frac{1}{\sqrt{d_G(u)^2 + d_G(e)^2}}.$$

We can express the multiplicative modified *KG* Sombor index as

$$mKGII(G) = \prod_{uv\in E(G)} \left[\frac{1}{\sqrt{d_G(u)^2+(d_G(u)+d_G(v)-2)^2}} + \frac{1}{\sqrt{d_G(v)^2+(d_G(u)+d_G(v)-2)^2}}\right].$$

Recently, some multiplicative indices were studied in [30, 31].

In this paper, we compute the multiplicative *KG* Sombor index, multiplicative modified *KG* Sombor index of certain networks such as chain silicate, silicate, hexagonal and oxide networks.

2. Results for Chain Silicate Networks

Silicates are very important elements of Earth's crust. Sand and several minerals are constituted by silicates. A family of chain silicate network is symbolized by CS_n and is obtained by arranging n□2 tetrahedral linearly, see Figure 1.

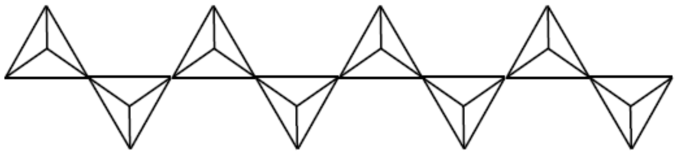

Fig. 1 Chain silicate network

Let G be the graph of a chain silicate network CS_n with $3n+1$ vertices and $6n$ edges. In G, by calculation, there are three types of edges based on the degree of end vertices of each edge as follows:

$E_1 = \{uv$ □ $E(G) \mid d_G(u) = d_G(v) = 3\}$, $|E_1| = n + 4$.

$E_2 = \{uv$ □ $E(G) \mid d_G(u) = 3, d_G(v) = 6\}$, $|E_2| = 4n - 2$.

$E_3 = \{uv$ □ $E(G) \mid d_G(u) = d_G(v) = 6\}$, $|E_3| = n - 2$.

In the following theorem, we compute the multiplicative *KG* Sombor index of a chain silicate network.

Theorem 1. The multiplicative *KG* Sombor index of a chain silicate network is

$$KGII(CS_n) = (10)^{n+4} \times \left(\sqrt{58}+\sqrt{85}\right)^{4n-2} \times \left(4\sqrt{34}\right)^{n-2}.$$

Proof: By the definition of multiplicative *KG* Sombor index and cardinalities of the edge partitions of CS_n, we have

$$KGII(CS_n) = \prod_{uv\in E(CS_n)}\left[\sqrt{d_G(u)^2 + (d_G(u) + d_G(v) - 2)^2} + \sqrt{d_G(v)^2 + (d_G(u) + d_G(v) - 2)^2}\right]$$

$$= \left[\sqrt{3^2 + (3 + 3 - 2)^2} + \sqrt{3^2 + (3 + 3 - 2)^2}\right]^{n+4} \times \left[\sqrt{3^2 + (3 + 6 - 2)^2} + \sqrt{6^2 + (3 + 6 - 2)^2}\right]^{4n-2}$$

$$\times \left[\sqrt{3^2 + (3 + 6 - 2)^2} + \sqrt{6^2 + (3 + 6 - 2)^2}\right]^{4n-2}$$

gives the desired result after simplification.

In Theorem 2, we compute the multiplicative modified *KG* Sombor index of a chain silicate network.

Theorem 2. The multiplicative *KG* Sombor index of a chain silicate network is

$$mKGII(CS_n) = \left(\frac{2}{5}\right)^{n+4} \times \left(\frac{1}{\sqrt{58}}+\frac{1}{\sqrt{85}}\right)^{4n-2} \times \left(\frac{1}{\sqrt{34}}\right)^{n-2}.$$

Proof: By the definition of multiplicative *KG* Sombor index and cardinalities of the edge partitions of CS_n, we have

$$mKGII(CS_n) = \prod_{uv\in E(CS_n)} \left[\frac{1}{\sqrt{d_G(u)^2+(d_G(u)+d_G(v)-2)^2}} + \frac{1}{\sqrt{d_G(v)^2+(d_G(u)+d_G(v)-2)^2}}\right]$$

$$= \left[\frac{1}{\sqrt{3^2+(3+3-2)^2}} + \frac{1}{\sqrt{3^2+(3+3-2)^2}}\right]^{n+4} \times \left[\frac{1}{\sqrt{3^2+(3+6-2)^2}} + \frac{1}{\sqrt{6^2+(3+6-2)^2}}\right]^{4n-2}$$

$$\times \left[\frac{1}{\sqrt{6^2+(6+6-2)^2}} + \frac{1}{\sqrt{6^2+(6+6-2)^2}}\right]^{4n-2}.$$

After simplification, we establish the desired result.

3. Results for Silicate Networks

Silicates are obtained by fusing metal oxide or metal carbonates with sand. A silicate network is denoted by SL_n, where n is the number of hexagons between the center and boundary of SL_n. A 2-dimensional silicate network of dimension two is shown in Fig. 2.

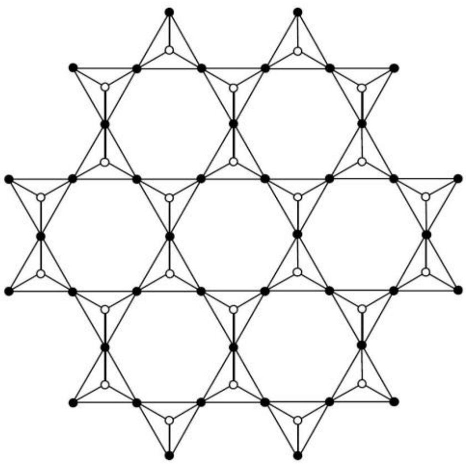

Fig. 2 Silicate network of dimension two

Let G be the graph of a silicate network SL_n. The graph G has $15n^2 + 3n$ vertices and $36n^2$ edges. In G, by calculation, there are three types of edges based on the degree of end vertices of each edge as follows:

$E_1 = \{uv \in E(G) \mid d_G(u) = d_G(v) = 3\}$, $\qquad |E_1| = 6n$.

$E_2 = \{uv \in E(G) \mid d_G(u) = 3, d_G(v) = 6\}$, $\qquad |E_2| = 18n^2 + 6n$.

$E_3 = \{uv \in E(G) \mid d_G(u) = d_G(v) = 6\}$, $\qquad |E_3| = 18n^2 - 12n$.

In the following theorem, we compute the multiplicative KG Sombor index of a silicate network.

Theorem 3. The multiplicative KG Sombor index of a silicate network is

$$KGII(SL_n) = (10)^{6n} \times \left(\sqrt{58} + \sqrt{85}\right)^{18n^2+6n} \times \left(4\sqrt{34}\right)^{18n^2-12n}.$$

Proof: By the definition of multiplicative KG Sombor index and cardinalities of the edge partitions of SL_n, we have

$$KGII(SL_n) = \prod_{uv\in E(SL_n)}\left[\sqrt{d_G(u)^2 + (d_G(u) + d_G(v) - 2)^2} + \sqrt{d_G(v)^2 + (d_G(u) + d_G(v) - 2)^2}\right]$$

$$= \left[\sqrt{3^2 + (3+3-2)^2} + \sqrt{3^2 + (3+3-2)^2}\right]^{6n} \times \left[\sqrt{3^2 + (3+6-2)^2} + \sqrt{6^2 + (3+6-2)^2}\right]^{18n^2+6n}$$

$$\times \left[\sqrt{3^2 + (3+6-2)^2} + \sqrt{6^2 + (3+6-2)^2}\right]^{18n^2-12n}$$

gives the desired result after simplification.

In the next theorem, we compute the multiplicative modified KG Sombor index of a silicate network.

Theorem 4. The multiplicative *KG* Sombor index of a silicate network is

$$mKGII(SL_n) = \left(\frac{2}{5}\right)^{6n} \times \left(\frac{1}{\sqrt{58}} + \frac{1}{\sqrt{85}}\right)^{18n^2+6n} \times \left(\frac{1}{\sqrt{34}}\right)^{18n^2-12n}.$$

Proof: By the definition of multiplicative *KG* Sombor index and cardinalities of the edge partitions of SL_n, we have

$$mKGII(SL_n) = \prod_{uv\in E(SL_n)} \left[\frac{1}{\sqrt{d_G(u)^2+(d_G(u)+d_G(v)-2)^2}} + \frac{1}{\sqrt{d_G(v)^2+(d_G(u)+d_G(v)-2)^2}}\right]$$

$$= \left[\frac{1}{\sqrt{3^2+(3+3-2)^2}} + \frac{1}{\sqrt{3^2+(3+3-2)^2}}\right]^{6n} \times \left[\frac{1}{\sqrt{3^2+(3+6-2)^2}} + \frac{1}{\sqrt{6^2+(3+6-2)^2}}\right]^{18n^2+6n}$$

$$\times \left[\frac{1}{\sqrt{6^2+(6+6-2)^2}} + \frac{1}{\sqrt{6^2+(6+6-2)^2}}\right]^{18n^2-12n}.$$

After simplification, we obtain the desired result.

4. Results for Hexagonal Networks

It is known that there exist three regular plane tilings with composition of some kind of regular polygons such as triangular, hexagonal and square. Triangular tiling is used in the construction of hexagonal networks. This network is symbolized by HX_n, where n is the number of vertices in each side of hexagon. A 6-dimensional hexagonal network is shown in Figure 3.

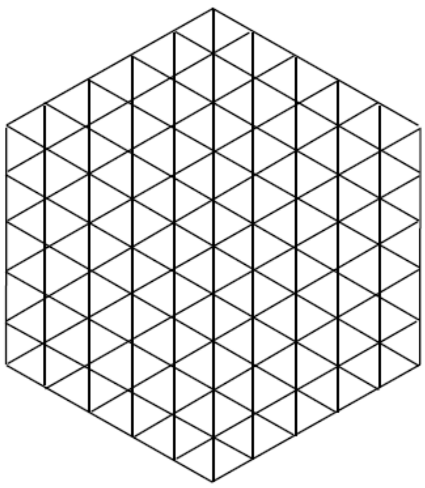

Fig. 3 Hexagonal network of dimension six

Let G be the graph of a hexagonal network HX_n. The graph G has $3n^2–3n+1$vertices and $9n^2–15n+6$ edges. In G, by calculation, there are five types of edges based on the degree of end vertices of each edge as follows:

$E_1 = \{uv \in E(G) \mid d_G(u) = 3, d_G(v) = 4\}$, $|E_1| = 12$.

$E_2 = \{uv \in E(G) \mid d_G(u) = 3, d_G(v) = 6\}$, $|E_2| = 6$.

$E_3 = \{uv \in E(G) \mid d_G(u) = d_G(v) = 4\}$, $|E_3| = 6n – 18$.

$E_4 = \{uv \in E(G) \mid d_G(u) = 4, d_G(v) = 6\}$, $|E_4| = 12n – 24$.

$E_5 = \{uv \in E(G) \mid d_G(u) = d_G(v) = 6\}$, $|E_5| = 9n^2 – 33n + 30$.

In the following theorem, we compute the multiplicative *KG* Sombor index of a hexagonal network.

Theorem 5. The multiplicative *KG* Sombor index of a hexagonal network is

$$KGII(HX_n) = \left(\sqrt{34}+\sqrt{41}\right)^{12} \times \left(\sqrt{58}+\sqrt{85}\right)^{6} \times \left(4\sqrt{13}\right)^{6n-18} \times \left(4\sqrt{5}+10\right)^{12n-24} \times \left(4\sqrt{34}\right)^{9n^2-33n+30}.$$

Proof: By the definition of multiplicative *KG* Sombor index and cardinalities of the edge partitions of HX_n, we have

$$KGII(HX_n) = \prod_{uv\in E(HX_n)}\left[\sqrt{d_G(u)^2+(d_G(u)+d_G(v)-2)^2}+\sqrt{d_G(v)^2+(d_G(u)+d_G(v)-2)^2}\right]$$

$$= \left[\sqrt{3^2+(3+4-2)^2}+\sqrt{4^2+(3+4-2)^2}\right]^{12} \times \left[\sqrt{3^2+(3+6-2)^2}+\sqrt{6^2+(3+6-2)^2}\right]^{6}$$

$$\times \left[\sqrt{4^2+(4+4-2)^2}+\sqrt{4^2+(4+4-2)^2}\right]^{6n-18} \times \left[\sqrt{4^2+(4+6-2)^2}+\sqrt{6^2+(4+6-2)^2}\right]^{12n-24}$$

$$\times \left[\sqrt{6^2+(6+6-2)^2}+\sqrt{6^2+(6+6-2)^2}\right]^{9n^2-33n+30}$$

gives the desired result after simplification.

In the next theorem, we compute the multiplicative modified *KG* Sombor index of a hexagonal network.

Theorem 6. The multiplicative *KG* Sombor index of a hexagonal network is

The multiplicative *KG* Sombor index of a hexagonal network is

$$mKGII(HX_n) = \left(\frac{1}{\sqrt{34}}+\frac{1}{\sqrt{41}}\right)^{12} \times \left(\frac{1}{\sqrt{58}}+\frac{1}{\sqrt{85}}\right)^{6} \times \left(\frac{1}{\sqrt{13}}\right)^{6n-18} \times \left(\frac{1}{4\sqrt{5}}+\frac{1}{10}\right)^{12n-24} \times \left(\frac{1}{\sqrt{34}}\right)^{9n^2-33n+30}.$$

Proof: By the definition of multiplicative *KG* Sombor index and cardinalities of the edge partitions of HX_n, we have

$$mKGII(HX_n) = \prod_{uv\in E(HX_n)}\left[\frac{1}{\sqrt{d_G(u)^2+(d_G(u)+d_G(v)-2)^2}}+\frac{1}{\sqrt{d_G(v)^2+(d_G(u)+d_G(v)-2)^2}}\right]$$

$$= \left[\frac{1}{\sqrt{3^2+(3+4-2)^2}}+\frac{1}{\sqrt{4^2+(3+4-2)^2}}\right]^{12} \times \left[\frac{1}{\sqrt{3^2+(3+6-2)^2}}+\frac{1}{\sqrt{6^2+(3+6-2)^2}}\right]^{6}$$

$$\times \left[\frac{1}{\sqrt{4^2+(4+4-2)^2}}+\frac{1}{\sqrt{4^2+(4+4-2)^2}}\right]^{6n-18} \times \left[\frac{1}{\sqrt{4^2+(4+6-2)^2}}+\frac{1}{\sqrt{6^2+(4+6-2)^2}}\right]^{12n-24}$$

$$\times \left[\frac{1}{\sqrt{6^2+(6+6-2)^2}}+\frac{1}{\sqrt{6^2+(6+6-2)^2}}\right]^{9n^2-33n+30}.$$

After simplification, we get the desired result.

5. Results for Oxide Networks

Oxide networks are of vital importance in the study of silicate networks. An oxide network of dimension *n* is denoted by OX_n. A 5-dimensional oxide network is presented in Figure 4.

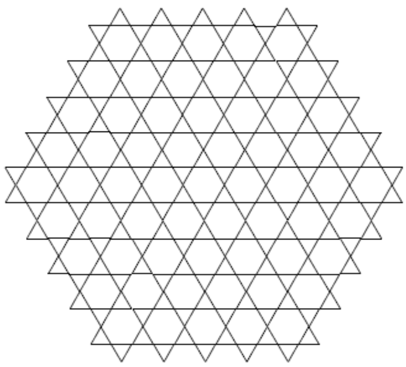

Fig. 4 Oxide network of dimension 5

Let G be the graph of an oxide network OX_n. By calculation, we obtain that G has $9n^2+3n$ vertices and $18n^2$ edges. In G, by calculation, there are two types of edges based on the degree of end vertices of each edge as follows:

$E_1 = \{uv \in E(G) \mid d_G(u) = 2, d_G(v) = 4\}$, $|E_1| = 12n$.

$E_2 = \{uv \in E(G) \mid d_G(u) = d_G(v) = 4\}$, $|E_2| = 18n^2 - 12n$.

In the following theorem, we compute the multiplicative KG Sombor index of an oxide network.

Theorem 7. The multiplicative KG Sombor index of an oxide network is

$$KGII(OX_n) = \left(2\sqrt{5} + 4\sqrt{2}\right)^{12n} \times \left(4\sqrt{13}\right)^{18n^2-12n}.$$

Proof: By the definition of multiplicative KG Sombor index and cardinalities of the edge partitions of OX_n, we have

$$KGII(OX_n) = \prod_{uv\in E(OX_n)}\left[\sqrt{d_G(u)^2 + (d_G(u)+d_G(v)-2)^2} + \sqrt{d_G(v)^2 + (d_G(u)+d_G(v)-2)^2}\right]$$

$$= \left[\sqrt{2^2+(2+4-2)^2} + \sqrt{4^2+(2+4-2)^2}\right]^{12n} \times \left[\sqrt{4^2+(4+4-2)^2} + \sqrt{4^2+(4+4-2)^2}\right]^{18n^2-12n}$$

gives the desired result after simplification.

In Theorem 8, we compute the multiplicative modified KG Sombor index of an oxide network.

Theorem 8. The multiplicative KG Sombor index of an oxide network is

$$mKGII(OX_n) = \left(\frac{1}{2\sqrt{5}} + \frac{1}{4\sqrt{2}}\right)^{12n} \times \left(\frac{1}{\sqrt{13}}\right)^{18n^2-12n}.$$

Proof: By the definition of multiplicative KG Sombor index and cardinalities of the edge partitions of OX_n , we have

$$mKGII(OX_n) = \prod_{uv\in E(OX_n)}\left[\frac{1}{\sqrt{d_G(u)^2+(d_G(u)+d_G(v)-2)^2}} + \frac{1}{\sqrt{d_G(v)^2+(d_G(u)+d_G(v)-2)^2}}\right]$$

$$= \left[\frac{1}{\sqrt{2^2+(2+4-2)^2}} + \frac{1}{\sqrt{4^2+(2+4-2)^2}}\right]^{12n} \times \left[\frac{1}{\sqrt{4^2+(4+4-2)^2}} + \frac{1}{\sqrt{4^2+(4+4-2)^2}}\right]^{18n^2-12n}.$$

After simplification, we establish the desired result.

6. Conclusion

In this paper, we have introduced the multiplicative KG Sombor index, multiplicative modified KG Sombor index of a graph. Furthermore, we have determined these multiplicative KG Sombor indices for chain silicate, silicate, hexagonal and oxide networks.

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