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Original Article

α(gg)*-Closed Sets in Topological Spaces

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Abstract *- In this paper we introduce the concept of alpha generalization of generalized star closed sets in topological spaces. Also, we investigated its relation among other closed sets. Further, we derived some of its characteristics.*

Keywords *- α(gg)*-closed sets, (gg)*-open sets, α-closure.*

2020 Subject Classification: *54A05.*

I. INTRODUCTION

In 1970, Levine [34] introduced the concept of generalized closed sets in topology.in 2017, Basavaraj, M. Ittangi and H. G. Govardhana Reddy [5] introduced gg-closed sets in topological spaces. in 2018, I. Christal Bai and T. Shyla Isac Mary [10] introduced (gg)*-closed sets in topological spaces. in this paper, a new class of closed set called alpha generalization of generalized star- closed set is introduced. the concept of alpha generalization of generalized star- closed set and its characteristics are analyzed in this paper.

II. PRELIMINARIES

Throughout this paper (X,τ) represents the topological spaces on which no separation axioms are assumed unless otherwise mentioned. *A* being a subset of a topological space (X,τ), *cl*(A), *int*(A) denote the closure of A and interior of A respectively. Replace (X,τ) with X if there is no chance of confusion.

Definition 2.1. A subset A of a topological space (X,τ) is called

- **(i)** pre-open [18] if A ⊆ *int cl*(A) and pre-closed if *cl int*(A) ⊆ A.
- **(ii)** semi-open [34] if A ⊆ *cl int*(A) and semi-closed if *int cl*(A) ⊆ A.
- **(iii)** semi-pre-open [2] if A ⊆ *cl int cl*(A) and semi-pre-closed if *int cl int*(A) ⊆ A.
- **(iv)** α-open [20] if A ⊆ *int cl int*(A) and α-closed if *cl int cl*(A) ⊆ A.
- **(v)** regular-open [30] if A = *int cl*(A) and regular-closed if *cl int*(A) = A.
- **(vi)** b-open [3] if A ⊆ *cl int*(A) ∪ *int cl*(A) and b-closed if *cl int*(A) ∩ *int cl*(A) ⊆ A.
- **(vii)** π-open [20] if A is the union of regular open sets and π-closed if A is the intersection of regular closed sets.

the alpha-closure (resp. semi-closure, resp. semi-pre-closure, resp. pre-closure, resp. b-closure) of a subset of A of a topological space (X,τ) is the intersection of all alpha-closed (resp. semiclosed, resp. semi-pre-closed, resp. pre-closed, resp. b-closed) sets containing A and is denoted by α*cl*A (resp. *scl*A, resp. *spcl*A, resp. *pcl*A, resp. *bcl*A).

Definition 2.2. A subset A of a a topological space (X,τ) is called

- **(i)** regular semi-open [9] if there is a regular open set U such that U ⊆ A ⊆ *cl*(U).
- **(ii)** generalized-closed [16] (briefly g-closed) if *cl*(A) ⊆ U whenever A ⊆ U and U is open.
- **(iii)** generalization of generalized closed [5](briefly gg-closed) if *gcl*(A) ⊆ U whenever A ⊆ U and U is regular semi-open.
- **(iv)** generalization of generalized star closed[10] (briefly (gg)*-closed) if *rcl*(A) ⊆ U whenever A ⊆ U and U is gg-open.
- **(v)** generalized semi-closed [4] (briefly gs-closed) if *scl*(A) ⊆ U whenever A ⊆ U and U is open.
- **(vi)** α-generalized-closed [17] (briefly αg-closed) if α*cl*(A) ⊆ U whenever A ⊆ U and U is open.

(vii) $g^{\#}$-closed [34] if *cl*(A) ⊆ U whenever A ⊆ U and U is αg-open.
(viii) generalized semi-pre-closed [11] (briefly gsp-closed) if *spcl*(A) ⊆ U whenever A ⊆ U and U is open.
(ix) generalized b-closed [1] (briefly gb-closed) if *bcl*(A) ⊆ (U) whenever A ⊆ U and U is open.
(x) semi generalized-closed [8] (briefly sg-closed) if *scl*(A) ⊆ U whenever A ⊆ U and U is semi-open.
(xi) strongly generalized semi-pre-closed [24] (briefly (gsp)* closed) if *cl*(A) ⊆ U whenever A ⊆ U and U is gsp-open.
(xii) weakly-closed [29] (briefly w-closed) if *cl*(A) ⊆ U whenever A ⊆ U and U is semi-open.
(xiii) $\hat{g}^*$s-closed [25] if *cl*(A) ⊆ U whenever A ⊆ U and U is ĝ-open.
(xiv) strongly generalized closed [32] (briefly g*-closed) if *cl*(A) ⊆ U whenever A ⊆ U and U is g-open.
(xv) *g closed [32] if *scl*(A) ⊆ U whenever A ⊆ U and U is semi-open.
(xvi) weakly semi-closed [6] (briefly ws-closed) if *scl*(A) ⊆ U whenever A ⊆ U and U is w-open.
(xvii) generalized alpha regular-closed [25] (briefly gαr-closed) if *αcl*(A) ⊆U whenever A ⊆ U and U is regular-open.
(xviii) generalized pre-regular closed [13] (briefly gpr-closed) if *pcl*(A) ⊆U whenever A ⊆ U and U is regular-open.
(xix) generalized semi-pre-regular closed[19] (briefly gspr-closed) if *spcl*(A) ⊆U whenever A ⊆U and U is regular-open.
(xx) regular weakly-closed [7] (briefly rw-closed) if *cl*(A) ⊆ U whenever A ⊆U and U is regular semi-open.
(xxi) generalised star semi-closed [26] (briefly g^*s-closed) if *scl*(A) ⊆ U whenever A ⊆ U and U is gs-open.
(xxii) generalized star b-closed [21] (briefly g^*b-closed) if *bcl*(A) ⊆ U whenever A ⊆ U and U is g-open.
(xxiii) gs*closed or (gs)*-closed [12] if *cl*(A) ⊆ U whenever A ⊆ U and U is gs-open.
(xxiv) R*-closed [14] if r*cl*(A) ⊆ U whenever A ⊆ U and U is regular semi-open.
(xxv) generalized star b-omega closed [22] (briefly g*bω-closed) if *bcl*(A) ⊆ U whenever A ⊆ U and U is gs-open.
(xxvi) α-generalized regular closed [33] (briefly αgr-closed) if *αcl*(A) ⊆ U whenever A ⊆ U and U is regular open.

III. α(GG)*-CLOSED SETS

Definition 3.1. A set A of a topological space (X, τ) is called alpha generalization of **generalized star closed** (briefly ***α*****(gg)*-closed**) if αcl(A) ⊆ U whenever A⊆U and U is (gg)*- open in (X, τ).the set of all α(gg)*-closed sets in (X, τ) is denoted by α(GG)*C .

Example 3.2. Let X={a, b, c, d}with topology τ ={∅,{a},{b},{a, b},{a, b, c}, X}.Then ∅,{c},{d},{c,d},{a, d}, {b, d}, {a, b, c}, {b, c, d}, {a, b, d},{a, c, d} and X are α(gg)*-closed.

Theorem 3.3.

(i) Every closed set is α(gg)*-closed
(ii) Every α-closed set is α(gg)*-closed.
(iii) Every regular closed set is α(gg)*-closed.
(iv) Every π-closed set is α(gg)*-closed.
(v) Every g*-closed set is α(gg)*-closed.
(vi) Every (gs)*closed set is α(gg)*-closed.
(vii) Every (gsp)*closed set is α(gg)*-closed.

(viii) **Proof.**
(i) Let A be any closed subset of a space X. Let A ⊆ U and U is (gg)*-open in X. Since A is closed, cl(A)=A ⊆ U. But αcl(A) ⊆ cl(A) ⊆ U. Therefore αcl(A) ⊆ U. Hence A is α(gg)*-closed set in X.
(ii) Let A be any α-closed subset of a space X. Let A⊆ U and U is (gg)*-open in X. Since A is α-closed, αcl(A) =A ⊆ U. Therefore αcl(A) ⊆ U. Hence A is α(gg)*-closed set in X.
(iii) Let A be any regular closed subset of a space X. Let A ⊆ U and U is (gg)*-open in X. Since A is regular closed, rcl(A) = A ⊆ U. But αcl(A) ⊆ rcl(A) ⊆ U. Therefore αcl(A) ⊆ U. Hence A is α(gg)*-closed set in X.
(iv) Let A be any π-closed subset of a space X. Let A ⊆ U and U is (gg)*-open in X. Since A is π-closed, πcl(A) =A⊆ U. But αcl(A) ⊆ πcl(A) ⊆ U. Therefore αcl(A) ⊆ U. Hence A is α(gg)*-closed set in X.
(v) Let A be any g*-closed subset of a space X. Let A ⊆ U and U is (gg)*-open in X. Since every (gg)*-open is g-open [10] and since U is g-open, cl(A) ⊆ A ⊆ U. But αcl(A) ⊆ cl(A) ⊆ U. Therefore αcl(A) ⊆ U. Hence A is α(gg)*-closed set in X.
(vi) Let A be any (gs)* closed subset of a space X. Let A⊆ U and U is (gg)*-open in X. Since every (gg)*-open is gs-open [10] and since A is (gs)* closed, cl(A) ⊆ A ⊆ U. But αcl(A) ⊆ cl(A) ⊆ U. Therefore αcl(A) ⊆ U. Hence A is α(gg)*-closed set in X.

(vii) Let A be any (gsp)* closed subset of a space X. Let A ⊆ U and U is (gg)*-open in X. Since every (gg)*-open is gsp-open [10] and since A is (gsp)* closed, cl(A) ⊆A⊆ U. But αcl(A) ⊆ cl(A) ⊆ U. Therefore αcl(A) ⊆ U. Hence A is α(gg)*-closed set in X.

Remark 3.4. the converses of the above theorems need not be true in general as seen from the following example.

Example 3.5. Let X={a, b, c, d}with topology τ ={∅,{a},{b},{a, b},{a, b, c}, X}. Then

(i) {c} is α(gg)*-closed but not closed.
(ii) {a,d} is α(gg)*-closed but not α-closed.
(iii) {c} is α(gg)*-closed but not regular closed.
(iv) {c} is α(gg)*-closed but not π-closed.
(v) {c} is α(gg)*-closed but not g*-closed.
(vi) {c} is α(gg)*-closed but not (gs)*-closed.
(vii) {c} is α(gg)*-closed but not (gsp)* closed.

Theorem 3.6.

(i) Every α(gg)*-closed set is gs-closed.
(ii) Every α(gg)*-closed set is gb-closed.
(iii) Every α(gg)*-closed set is gsp-closed.
(iv) Every α(gg)*-closed set is gpr-closed.
(v) Every α(gg)*-closed set is gspr-closed.
(vi) Every α(gg)*-closed set is gαr-closed.

Proof.

(i) Let A be any α(gg)*-closed subset of a space X. Let A ⊆ U and U is open in X. Since every open set is (gg)* open, U is (gg)* open. Also, since A is α(gg)*-closed, αcl(A) ⊆ U. But scl(A) ⊆ αcl(A) ⊆ U. Therefore, scl(A) ⊆ U. Hence A is gs-closed set in X.
(ii) Let A be any α(gg)*-closed subset of a space X. Let A ⊆ U and U is open in X. Since every open set is (gg)*-open, U is (gg)*-open. Also, since A is α(gg)*-closed, αcl(A) ⊆ U. But bcl(A) ⊆ αcl(A) ⊆ U. Therefore, bcl(A) ⊆ U. Hence A is gb-closed set in X.
(iii) Let A be any α(gg)*-closed subset of a space X. Let A ⊆ U and U is open. Since every open set is (gg)*-open, U is (gg)*-open. Also, since A is α(gg)*-closed, αcl(A) ⊆ U. But spcl(A) ⊆ αcl(A) ⊆ U. Therefore, spcl(A) ⊆ U. Hence A is gsp-closed set in X.
(iv) Let A be any α(gg)*-closed subset of a space X. Let A ⊆ U and U is regular-open in X. Since every regular-open set is (gg)*-open, U is (gg)*-open, Also, since A is α(gg)*-closed, αcl(A) ⊆ U. But pcl(A) ⊆ αcl(A) ⊆ U. Therefore, pcl(A) ⊆ U. Hence A is gpr-closed set in X.
(v) Let A be any α(gg)*-closed subset of a space X. Let A ⊆ U and U is regular-open in X. Since every regular-open set is (gg)*-open, U is (gg)*-open. Also, since A is α(gg)*-closed, αcl(A) ⊆ U. But spcl(A) ⊆ αcl(A) ⊆ U. Therefore, spcl(A) ⊆ U. Hence A is gspr-closed set in X.
(vi) Let A be any α(gg)*-closed subset of a space X. Let A ⊆ U and U is regular-open in X. Since every regular-open set is (gg)*-open, U is (gg)*-open. Also, since A is α(gg)*-closed, αcl(A) ⊆ U. Hence A is gαr-closed set in X.

Remark 3.7. the converses of the above theorems need not be true in general as seen from the following example.

Example 3.8. Let X={a, b, c, d}with topology τ ={∅,{a},{c, d},{a, c, d}, X}. Then

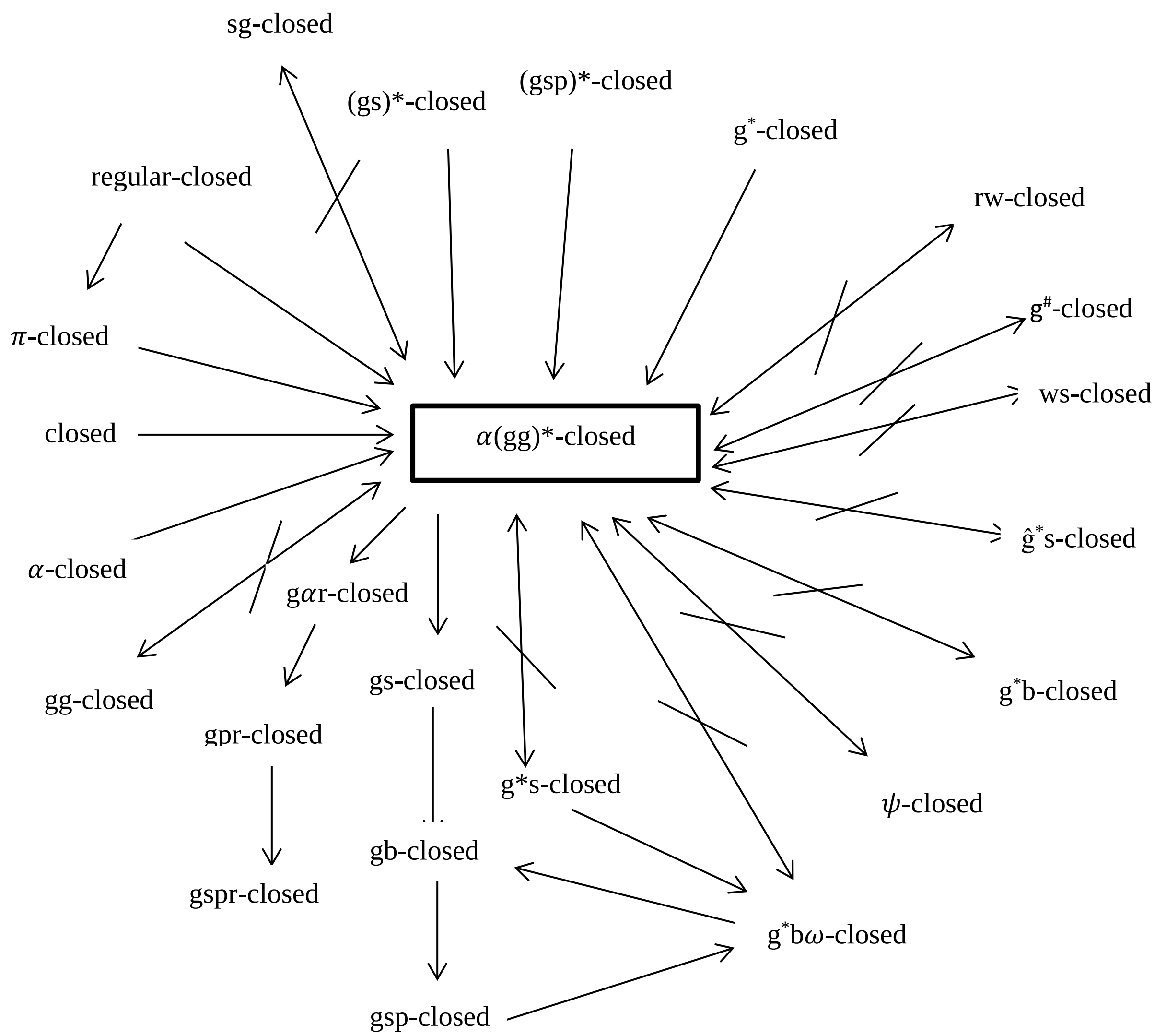
(i) {a} is gs-closed but not α(gg)*-closed.
(ii) {a} is gb closed but not α(gg)*-closed.
(iii) {a} is gsp-closed but not α(gg)*-closed.
(iv) {c} is gpr-closed but not α(gg)*-closed.
(v) {a} is gspr-closed but not α(gg)*-closed.
(vi) {c} is gαr -closed but not α(gg)*-closed.

the concept "α(gg)*-closed" is independent from the concepts "rw-closed", "sg-closed", "$g^{\#}$-closed", "R^*-closed", "g^*s-closed", "g^*b-closed", "gg-closed", "$g^*b\omega$-closed", "$\hat{g}^*$s-closed", "ψ-closed", "ws-closed".

Example 3.9. Let X={a, b, c, d}with topology τ ={∅,{a},{b},{a, b},{a, b, c}, X}.

(i) {c} is α(gg)*-closed but not rw-closed and {a, b} is rw-closed but not α(gg)*-closed.
(ii) {a, b, c} is α(gg)*-closed but not sg-closed and {a, b} is sg-closed but not α(gg)*-closed.
(iii) {c} is α(gg)*-closed but not $g^{\#}$-closed and {a, b} is $g^{\#}$-closed but not α(gg)*-closed.
(iv) {c} is α(gg)*-closed but not R^*-closed and {a, b} is R^*-closed but not α(gg)*-closed.
(v) {c} is α(gg)*-closed but not g^*s-closed and {a, b} is g^*s-closed but not α(gg)*-closed.
(vi) {a, b, c} is α(gg)*-closed but not g^*b -closed and {a} is g^*b -closed but not α(gg)*-closed.
(vii) {c} is α(gg)*-closed but not gg-closed and {a, b} is gg-closed but not α(gg)*-closed.
(viii) {a, b, c} is α(gg)*-closed but not $g^*b\omega$ -closed and {a} is $g^*b\omega$ -closed but not α(gg)*-closed.
(ix) {a, b, c} is α(gg)*-closed but not $\hat{g}^*$s-closed -closed and {a} is $\hat{g}^*$s-closed -closed but not α(gg)*-closed.
(x) {a, b, c} is α(gg)*-closed but not ψ -closed and {a} is ψ -closed but not α(gg)*-closed.
(xi) {a, b, c} is α(gg)*-closed but not ws-closed and {a} is ws-closed but not α(gg)*-closed.

the above discussion lead to the following diagram, "A→B" means A implies B but not conversely and "A↮B" means A and B are independent of each other.



Theorem 3.10.the union of two α(gg)*-closed subsets of X is α(gg)*-closed.

Proof. Let A and B be any two α(gg)*-closed subsets of X. Let A ⊆ U and U is (gg)*-open, B ⊆ U and U is (gg)*-open. Then αcl(A) ⊆ U , αcl(B) ⊆ U. This implies that αcl(A) ∪ αcl(B) ⊆ U. We know that, αcl(A∪B)= αcl(A) ∪ αcl(B) ⊆ U[27]. Therefore αcl(A∪B) ⊆ U, whenever A∪B ⊆ U and U is (gg)*-open in X. Thus A∪B is α(gg)*-closed set in X.

Remark 3.11. Intersection of any two α(gg)*-closed sets need not be an α(gg)*-closed as seen from the following example.

Example 3.12. Let X={a, b, c, d} and τ ={∅,{a},{b},{a, b},{a, b, c}, X}. Let A={a, b, c} and {a, b, d} be two α(gg)*-closed sets in X. But A∩B ={a, b} is not an α(gg)*-closed set.

Theorem 3.13. If a subset A of X is α(gg)*-closed in X, if and only if αcl(A) \ A does not contain any non-empty (gg)*-closed set in X.

Proof. Let A be a α(gg)*-closed set in X and M be a (gg)*-closed subset of αcl(A) \ A. Then M⊆ αcl(A) ∩ (X\A) ⇒ M ⊆ αcl(A) and M ⊆ X \ A. M ⊆ X \ A ⇒ A ⊆ X \ M. Since A is α(gg)*-closed and X\ M is (gg)*-open, αcl(A) ⊆ X \ M. Then M ⊆ X \ αcl(A). But we have M ⊆ αcl(A). Therefore, M ⊆ (X \ αcl(A)) ∩ αcl(A)=∅. Thus M=∅. Hence αcl(A)\A does not contain any non-empty (gg)*-closed set in X. Conversely, suppose that αcl(A)\A does not contain any non-empty (gg)*-closed set in X. Let A ⊆ N and N be (gg)*- open. If αcl(A) is not a subset of N then αcl(A) ∩ N^c is a non-empty (gg)*-closed subset of αcl(A)\A, which is a contradiction. Therefore, αcl(A) ⊆ N and hence A is α(gg)*-closed.

Theorem 3.14. If a subset A is α(gg)*-closed set in X and A⊆ B⊆ αcl(A), then B is also α(gg)*-closed set in X.

Proof. Let A be a α(gg)*-closed set in X such that A⊆ B⊆ αcl(A). To prove B is also a α(gg)*-closed set in X**,** it is enough to prove that αcl(B) ⊆ U. Let U be a (gg)*-open set in X such that B ⊆ U. Since A ⊆ B and B ⊆ U, A ⊆ U. Also, since A is α(gg)*- closed, αcl(A) ⊆ U. Now, B ⊆ αcl(A) ⇒ αcl(B) ⊆ αcl[αcl(A)]=αcl(A) ⊆ U[31]. That is, αcl(B) ⊆ U. Therefore, B is a α(gg)*- closed set in X

Theorem 3.15. For every point x in a space X, X−{x} is α(gg)*-closed or (gg)*-open.

Proof.

Case (i): Suppose that X−{x} is not (gg)*-open. Then X is the only (gg)*-open set containing X−{x}. Then by using Definition: 3.1, αcl(X−{ x }) ⊆ X. Hence X−{ x } is α(gg)*- closed.

Case (ii): Suppose that X−{x} is not α(gg)*-closed. Then there exist a (gg)*-open set U containing X−{ x } such that αcl(X−{ x })⊈U. Therefore, αcl(X−{ x }) is either X−{ x } or X. If αcl(X−{ x })= X−{ x }, then X−{ x } is α-closed. By Theorem: 3.3(ii), every α-closed set is α(gg)*- closed, then X−{ x } is α(gg)*-closed. This is a contradiction to our assumption. Therefore, αcl(X−{ x }) = X. To prove that X−{ x } is (gg)*-open. Suppose that X−{ x } is not (gg)*-open. By case (i), X−{ x } is α(gg)*-closed. This is a contradiction to our assumption. Therefore, X−{ x } is (gg)*-open.

Theorem 3.16. A subset A of a space X is α(gg)*-closed if and only if for each A ⊆ N and N is (gg)*-open, there exists a α-closed set M such that A ⊆ M ⊆ N.

Proof. Suppose A is a α(gg)*-closed set and A⊆N and N is (gg)*-open. Then αcl(A) ⊆N. If we put M = αcl(A) , then M is α-closed set and A⊆ M ⊆ N. Conversely, assume that N is a (gg)*-open set containing A. Then there exists a α-closed set M such that A ⊆ M ⊆ N. Since αcl(A) is the smallest α-closed set containing A, we have A ⊆ αcl(A) ⊆ M. Also, since M ⊆ N, αcl (A) ⊆ N. Hence A is a α(gg)*-closed set in X.

Theorem 3.17. If A is α-closed and B is α(gg)*-closed subset of a space X then A∪B is α(gg)*-closed.

Proof. Let N be a (gg)*-open set containing A∪B. Then A⊆N and B⊆N. Since B is α(gg)*-closed and B⊆N, we have αcl(B)⊆N. Then A∪B⊆A∪ αcl(B)⊆N. Since A is α-closed, we have A ∪ αcl(B) is α-closed. Hence there exist a α-closed set A∪ αcl(B) such that A∪B ⊆ A∪ αcl(B) ⊆ N. Therefore, by Theorem: 3.16, A∪B is α(gg)*-closed.

Theorem 3.18.

(i) If A is closed and B is g*-closed subset of a space X, then A∪B is α(gg)*- closed.
(ii) If A is closed and B is (gs)*-closed subset of a space X, then A∪B is α(gg)*- closed.
(iii) If A is closed and B is (gsp)*-closed subset of a space X, then A∪B is α(gg)*- closed.

Proof.

(i) Since every closed set is α-closed, A is α-closed.and by Theorem: 3.3(v), B is α(gg)*-closed. Therefore by Theorem: 3.17, A∪B is α(gg)*-closed.
(ii) Since every closed set is α-closed, A is α-closed and by Theorem: 3.3(vi), B is α(gg)*-closed. Therefore by Theorem: 3.17, A∪B is α(gg)*-closed.
(iii) Since every closed set is α-closed, A is α-closed and by Theorem: 3.3(vii), B is α(gg)*-closed. Therefore by Theorem: 3.17, A∪B is α(gg)*-closed.

IV. CONCLUSION

In this paper, we focussed on alpha generalization of generalized star closed sets in topological spaces. Also, we established its relationships among other closed sets and examined some of its properties. in future, this idea can be extended to bitopological and tritopological spaces.

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