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ON (gsp)** - CLOSED SETS IN TOPOLOGICAL SPACES

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ABSTRACT

*In this paper we have introduced a new class of sets called (gsp)**-closed sets which is properly placed in between the class of (gsp)*-closed sets and (gsp)-closed sets. Properties and characterization of (gsp)**-closed sets are investigated.*

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1. INTRODUCTION:

Levine [4] introduced the class of g – closed sets in 1970. Dontchev[2] introduced gsp - closed sets. Pauline Mary Helan [12] introduced (gsp)* - closed sets in 2014. Sindhu Surya [15] introduced strongly (gsp)* - closed sets in 2015. The Purpose of this paper is to introduce the concept of (gsp)**-closed sets and (gsp)**-open sets in topological space and some of their properties and characterization are investigated.

2. PRELIMINARIES

In this chapter (X,τ) represent non-empty topological spaces on which no separations axioms are assumed unless otherwise mentioned. (X, τ) will be replaced by X if there is no changes of confusion. For a subset A of a space (X, τ), cl(A) and int(A) denote the closure and interior of A respectively.

The smallest semi-closed (resp. pre-closed and α-closed) set containing a subset A of (X, τ) is called the semi-closure (resp. pre-closure and α-closure) of A and is denoted by scl(A) (resp. pcl(A) and αcl(A)).

Definition 2.1: A subset A of a topological space (X, τ) is called
- (i) pre-open set [8] if A⊆int(cl(A)) and pre-closed if cl(int(A))⊆A.
- (ii) semi-open set [5] if A⊆cl(int(A)) and semi-closed if int(cl(A))⊆A.
- (iii) semi-pre-open set [1] if A⊆cl(int(cl(A))) and semi-pre-closed if int(cl(int(A)))⊆A.
- (iv) α-open set [10] if A⊆int(cl(int(A))) and α-closed if cl(int(cl(A))⊆A.
- (v) regular open set [8] if A=int(cl(A)) and regular closed if A=cl(int(A).

Definition 2.2: A subset A of a topological space (X, τ) is called
- (i) a generalized closed set[6] (briefly g-closed) if cl(A)⊆U, whenever A⊆U and U is open.
- (ii) a α-generalized closed set[7] (αg-closed) if αcl(A)⊆U, whenever A⊆U and U is open.
- (iii) generalized-semi-pre-regular-closed [3] (briefly gspr-closed) if spcl(A)⊆U, whenever A⊆U and U is regular open.
- (iv) generalized semi-closed [2] (briefly gs-closed) if scl(A)⊆U, whenever A⊆U and U is open.
- (v) generalized pre-closed [9](briefly gp-closed) if pcl(A)⊆U, whenever A⊆U and U is open.
- (vi) generalized semi- pre-closed [3](briefly gsp-closed) if spcl(A)⊆U, whenever A⊆U and U is open.
- (vii) generalized pre-regular closed[4](briefly gpr-closed) if pcl(A)⊆U, whenever A⊆U and U is regular open.
- (viii) weakly generalized closed [11](briefly wg-closed) if cl(int(A)) ⊆ U, whenever A⊆U and U is open.

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(ix) regular weakly generalized closed[14] (briefly rwg-closed) if cl(int(A))⊆U, whenever A⊆U and U is regular open.
(x) g*-closed [17] if cl(A)⊆U, whenever A⊆U and U is g-open.
(xi) g**- closed set[13] if cl(A)⊆U, whenever A⊆U and U is g*- open.
(xii) (gsp)*-closed[15] if cl(A)⊆U, whenever A⊆U and U is (gsp)-open.
(xiii) (g*p) closed set [17] if pcl⊆U, whenever A⊆U and U is g-open.
(xiv) sg**- closed set[16] if scl(A)⊆U, whenever A⊆U and U is g**open.
(xv)Strongly (gsp)* closed set[11] if cl(int(A))⊆U, whenever A⊆U and U is (gsp)-open.

The complements of the above mentioned closed sets are their respective open sets.

Remark 2.3: [17] Jankovic and Reilly pointed out that every singleton {x} of a space X is either nowhere dense or pre-open. This provides another decomposition $X=X_1\cup X_2$, where $X_1=\{x\in X/ \{x\}$ is nowhere dense$\}$ and $X_2=\{x\in X/ \{x\}$ is pre-open$\}$.

Definition 2.4: [17] The intersection of all gb-open sets containing A is called the gb-kernel of A and it is denoted by gb-ker(A).

Lemma 2.5: [17] For any subset A of X, $X_2\cap cl(A)\subseteq$ gb-ker(A).

Theorem 2.6: For a topological space (X, τ),
(i) Every (gsp)* open set is g-open.
(ii) Every open set is (gsp)*-open.
(iii) Every (gsp)*-open set is (gsp)-open.
(iv) Every semi-open set is (gsp)*-open.

3. (gsp)**-closed sets

In this chapter, we introduce (gsp)**-closed sets in topological spaces and obtain some of their properties.

Definition 3.1: A subset A of a topological space (X,τ) is said to be a (gsp)**-closed set if cl(A)⊆U, whenever A ⊆ U and U is (gsp)*-open. The family of all (gsp)**-closed sets in X is denoted by (gsp)**-C(X, τ).

Theorem 3.2: Every closed set is (gsp)**-closed.

Proof: Let A be a closed set. Let A ⊆ U and U is (gsp)*-open. Since A is closed, cl(A) = A ⊆ U. Thus, cl(A) ⊆ U whenever A⊆U and U is (gsp)*-open and therefore A is (gsp)**-closed.

The converse of the above theorem need not be true in general , as shown in the following example.

Example 3.3: Let X = {a, b, c} with τ = {ϕ, {a}, {a, b}, X}. Then A = {a, c} is (gsp)**-closed but not closed.

Theorem 3.4: Every (gsp)*-closed set is (gsp)**-closed.

Proof: Let A be a (gsp)*-closed set. Let A ⊆ U and U is (gsp)*-open. Since every (gsp)*-open set is (gsp)-open, U is (gsp)-open. Also since A is (gsp)*-closed, cl(A) ⊆ U whenever A ⊆ U and U is (gsp)*-open. Hence A is (gsp) **-closed.

The converse of the above theorem need not be true in general , as shown in the following example.

Example 3.5: Let X = {a, b, c}; τ = {ϕ, {a}, {a, c}, X}**,** Then A = {a, b} is (gsp)**-closed but not (gsp)*-closed.

Theorem 3.6: Every g*-closed set is (gsp) **-closed.

Proof: Let A be a g*-closed set. Let A ⊆ U and U is (gsp)*-open. Since every (gsp)*-open set is g-open and also since A is g*-closed, cl(A) ⊆ U whenever A ⊆ U and U is (gsp)*-open. Hence A is (gsp) **-closed.

The converse of the above theorem need not be true in general , as shown in the following example.

Example 3.7: Let X = {a, b, c} with τ = {ϕ,{a},{b,c}, X}, Then A = {b} is (gsp)**-closed but not g*-closed.

Theorem 3.8: Every (gsp)**-closed set is (gsp)-closed.

Proof: Let A be a (gsp)**-closed set. Let A⊆ U and U is open. Since every open set is (gsp)*-open and also since A is (gsp) **-closed, spcl(A) ⊆ cl(A) ⊆ U. This implies that spcl(A) ⊆ U whenever A ⊆ U and U is open. Hence A is (gsp)-closed.

The converse of the above theorem need not be true in general, as shown in the following example.

Example 3.9: Let X = {a, b, c} with τ = {ϕ, {a}, {c}, {a, c}, X}, Then A = {a} is (gsp)-closed but not (gsp)**-closed.

Theorem 3.10: Every (gsp)**-closed set is gpr-closed.

Proof: Let A be a (gsp)**-closed. Let A ⊆ U and U is regular–open. Since every regular-open set is (gsp)*-open and also since A is (gsp)**-closed, pcl(A) ⊆ cl(A) ⊆ U. This implies that pcl(A) ⊆ U whenever A ⊆ U and U is r-open. Hence A is gpr-closed.

The converse of the above theorem need not be true in general, as shown in the following example.

Example 3.11: Let X = {a, b, c} with τ = {ϕ, {a}, {a, b}, X}, Then A = {a} is gpr-closed but not (gsp)**-closed.

Theorem 3.12: Every (gsp)**-closed set is wg-closed.

Proof: Let A be a (gsp)**-closed. Let A ⊆ U and U is open. Since every open set is (gsp)*-open and also since A is (gsp)**-closed, cl(int(A)) ⊆ cl(A) ⊆ U. This implies that cl(int(A)) ⊆ U whenever A ⊆ U and U is open. Hence A is wg-closed.

The converse of the above theorem need not be true in general , as shown in the following example.

Example 3.13: Let X = {a, b, c} with τ = {ϕ, {a}, {a, b}, X}**,** Then A = {b} is wg-closed but not (gsp)**-closed.

Theorem 3.14: Every (gsp)**-closed set is rwg-closed.

Proof: Let A be a (gsp)**-closed set. Let A ⊆ U and U is regular open. Since every regular open set is(gsp)*-open and also since A is (gsp)**-closed, cl(int(A)) ⊆ cl(A) ⊆ U. This implies that cl(int(A)) ⊆ U whenever A ⊆ U and U is regular open. Hence A is rwg-closed.

The converse of the above theorem need not be true in general , as shown in the following example.

Example 3.15: Let X = {a, b, c} with τ = {ϕ, {a}, {c}, {a, c}, X}**,** Then A = {a, b} is rwg-closed but not (gsp)**-closed.

Theorem 3.16: Every (gsp)**-closed set is αg-closed.

Proof: Let A be a (gsp)**-closed set. Let A ⊆ U and U is open. Since every open set is (gsp)*-open and also since A is (gsp)**-closed, cl(A) ⊆ U. Since αcl(A) ⊆ cl(A) ⊆ U. This implies that αcl(A) ⊆ U whenever A ⊆ U and U is open. Therefore A is g-closed.

The converse of the above theorem need not be true in general, as shown in the following example.

Example 3.17: Let X = {a, b, c} with τ = {ϕ, {a}, {a, b}, X}**,** Then A = {b} is αg-closed but not (gsp)**-closed.

Theorem 3.18: Every (gsp)**-closed sets is gspr-closed.

Proof: Let A be a (gsp)**-closed. Let A ⊆ U and U is regular open. Since every regular open set is (gsp)*-open and also since A is (gsp)**-closed, cl(A) ⊆ U, spcl(A) ⊆ cl(A) ⊆ U. This implies that spcl(A) ⊆ U whenever A ⊆ U and U is regular-open. Hence A is gspr-closed.

The converse of the above theorem need not be true in general , as shown in the following example.

Example 3.19: Let X = {a, b, c} with τ = {ϕ, {a}, {c}, {a, c}, X}**;** Then A = {a} is gspr-closed but not (gsp)**-closed.

Theorem 3.20: Every (gsp)**-closed set is gs-closed.

Proof: Let A be a (gsp)**-closed set. Let A ⊆ U and U is open. Since every open set is (gsp)*-open and also since A is (gsp)**-closed, scl(A) ⊆ cl(A) ⊆ U. This implies that scl(A) ⊆ U, whenever A ⊆ U and U is open. Hence A is gs-closed.

The converse of the above proposition need not be true in general , as shown in the following example.

Example 3.21: Let X = {a, b, c} with τ = {ϕ, {a}, {c}, {a, c}, X}**,** Then A = {a} is gs-closed but not (gsp)**-closed.

Theorem 3.22: Every (gsp)**-closed set is gp-closed.

Proof: Let A be a(gsp)**-closed. Let A ⊆ U and U is open. Since every open set is (gsp)*-open and also since A is (gsp)**-closed , pcl(A) ⊆ cl(A) ⊆ U. This implies that, pcl(A) ⊆ U whenever A ⊆ U and U is open. Hence A is gp-closed.

The converse of the above theorem need not be true in general, as shown in the following example.

Example 3.23: Let X = {a, b, c} with τ = {ϕ, {a}, {a, b}, X}**,** Then A = {b} is gp-closed but not (gsp)**-closed.

Theorem 3.24: Every regular-closed set is (gsp)**-closed set.

Proof: let A be a regular closed. Let A ⊆ U and U is (gsp)**-open. Since every regular closed set is closed and by Theorem 3.2, A is (gsp)** - closed.

The converse of the above theorem need not be true in general, as shown in the following example.

Example 3.25: Let X = {a, b, c}; τ = {ϕ, {a}, {b, c}, X}**,** Then A = {b} is (gsp)**-closed but not regular closed.

Remark 3.26: (gsp)**-closed sets is independent of sg**-closed sets.

Example 3.27: Let X = {a, b, c}; τ = {ϕ, X, {a}, {a, c}}**,** Then A = {b} is sg**-closed but not (gsp)**-closed.

Example 3.28: Let X = {a, b, c}; τ = {ϕ, X, {a}, {sb, c}}**,** Then A = {b} is (gsp)**-closed but not sg**-closed.

4. Basic properties (gsp)**-closed sets

In this chapter we obtain some of its basic properties in topological spaces.

Theorem 4.1: If A is a (gsp)**-closed set of (X,τ) such that A⊆B⊆cl(A) then B is also a (gsp)**-closed set (X,τ).

Proof: Let U be (gsp)*-open set in X such that B ⊆ U. Then A ⊆ U Since A is (gsp)**-closed , cl(A) ⊆ U. Also, since B ⊆ cl(A). Therefore cl(B) ⊆ cl(cl(A)) = cl(A) ⊆ U. Thus, cl(B) ⊆ U whenever B ⊆ U and U is (gsp)*-open.
The converse of the above theorem need not be true in general, as shown in the following example.

Example 4.2: Let X = {a, b, c} with τ = {ϕ, {a}, {b, c}, X}. Let A = {b} and B = {a, b}. Then A and B are (gsp)**-closed set in X but A ⊆ B ⊈ cl(A).

Theorem 4.3: If a subset A of X is (gsp)**-closed set in X. Then cl(A)\A does not contain any non-empty (gsp)*-closed set in X.

Proof: Suppose A is (gsp)**-closed set in X. Suppose U is any non – empty (gsp)*-closed set such that cl(A)\A ⊇ U. Now, U ⊆ cl(A) \ A. Then U ⊆ cl(A)⋂A^c**.** This implies U ⊆ X \ A. Therefore, A ⊆ X \ U. Since U is (gsp)*-closed set, X \ U is (gsp)*-open in X. Since A is (gsp)**-closed in X , cl(A) ⊆ X \ U. This implies U ⊆ X \ cl(A). Also, U ⊆ cl(A) and therefore U ⊆ cl(A)⋂X\cl(A) = ϕ**.** This implies that U = ϕ**.** Which is a contradiction to U is non-empty. Hence cl(A) \ A does not contain any non-empty(gsp)*-closed set in X.

Corollary 4.4: If a subset A of a space X is (gsp)**-closed in X. Then cl(A) \ A does not contain any non-empty closed set in X.

Proof: Let A be a (gsp)** - closed subset of X. Suppose cl(A) – A contains a non – empty closed set F. By Theorem 3.2, F is (gsp)** - closed. Thus we have, cl(A) / A contains a non – empty (gsp)** - closed set. This contradicts the theorem 4.4. Hence cl(A) / A does not contain any (gsp)**- closed set.

Theorem 4.5: If A is (gsp)*-open and (gsp)**-closed set of X then A is a closed set of X.

Proof: Let A be (gsp)*-open and (gsp)**-closed set. Then cl(A) $\subseteq$ A and obviously A $\subseteq$ cl(A). Therefore A = cl(A). Hence A is closed.

Definition 4.6: Let X be a topological space and Y be a subspace of X. Then the subset A of Y is (gsp)* - open in Y if A = G $\cap$Y, where G is (gsp)* - open in X.

Theorem 4.7: Let A $\subseteq$ Y $\subseteq$ X and if A is a (gsp)**-closed set in X. Then A is a (gsp)**-closed relative to Y.

Proof: Given that A $\subseteq$ Y $\subseteq$ X and A is a (gsp)**- closed set in X. To prove that A is (gsp)** - closed set relative to Y. Let us assume that A $\subseteq$ Y$\cap$U, where U is (gsp)* - open in X. since A (gsp)**- closed set in X, then cl(A) $\subseteq$ U. That implies, Y$\cap$ cl(A) is the closure of A in Y and Y$\cap$U is (gsp)*- open in Y. Therefore cl(A) $\subseteq$ Y$\cap$U in Y. Hence A is (gsp)**- closed set relative to Y.

Theorem 4.8: Let A be a (gsp)**-closed in (X,τ). Then A is closed iff cl(A) \ A is a(gsp)*-closed.

Proof: Suppose A is closed in X. Then A = cl(A). Therefore cl(A) \ A = ϕ. Hence, A is (gsp)*-closed. Conversely, Suppose cl(A)-A is (gsp)*-closed set in X. Since A is (gsp)*-closed, By Theorem 4.1, cl(A)\A does not contain any non-empty (gsp)*-closed set in X. This implies that cl(A)\A = ϕ**.** Thus A=cl(A)**.** Hence A is closed.

Theorem 4.9: If A and B are (gsp)**-closed sets then A$\cup$B is also a (gsp)**-closed set.

Proof: Let A and B be (gsp)**-closed and A$\cup$B $\subseteq$ U and U is (gsp)*-open. Since A and B are (gsp)**-closed, cl(A) $\subseteq$ U and cl(B) $\subseteq$ U. Since cl(A$\cup$B) = cl(A)$\cup$cl(B) $\subseteq$ U. Therefore cl(A$\cup$B) $\subseteq$ U whenever A$\cup$B $\subseteq$ U and U is (gsp)*-open. Therefore A$\cup$B is a (gsp)**-closed set.

Definition 4.10: The intersection of all (gsp)*-open sets containing A is called the (gsp)*-kernel of A and it is denoted by (gsp)*-ker(A).

Theorem 4.11: A subset A of X is (gsp)**-closed iff cl(A)$\subseteq$(gsp)*-ker(A).

Proof:
Necessity: Let A be a (gsp)*-closed subset of X and x$\in$cl(A). Suppose x$\notin$(gsp)*-ker(A). Then there exists a (gsp)*-open set U containing A such that x$\notin$U. Since A is (gsp)**-closed set, then cl(A)$\subseteq$U. This implies that, x$\notin$cl(A), which is a contradiction to x$\in$cl(A). Therefore cl(A)$\subseteq$(gsp)*-ker(A).

Sufficiency: Suppose cl(A)$\subseteq$(gsp)*-ker(A). If U is any sb*-open set containing A, then (gsp)*-ker(A)$\subseteq$U. That implies, cl(A)$\subseteq$U. Hence A is (gsp)**-closed in X.

Remark 4.12: For any subset A of X, gb-ker(A)$\subseteq$(gsp)*-ker(A).

Theorem 4.13: For any subset A of X, $X_2$$\cap$cl(A)$\subseteq$(gsp)*-ker(A).

Proof: By Lemma 2.5 and Remark 4.12, $X_2$$\cap$cl(A)$\subseteq$(gsp)*-ker(A).

Theorem 4.14: A subset A of X is (gsp)**-closed if and only if $X_1$$\cap$cl(A)$\subseteq$A.

Proof: Necessity: Suppose that A is (gsp)**-closed and x$\in X_1$$\cap$cl(A). Then x$\in X_1$ and x$\in$cl(A). Since x$\in X_1$, then int(cl({x}))=$\emptyset$. Therefore {x} is semi-closed. By Theorem 2.4, {x} is (gsp)*-closed. If x does not belongs to A, then U=X–{x} is a (gsp)*-open set containing A and so cl(A)$\subseteq$U. Since x$\in$cl(A), x$\in$U. This is a contradiction to x not in U. Hence $X_1$$\cap$cl(A)$\subseteq$A.

Sufficiency: Let $X_1$$\cap$cl(A)$\subseteq$A. Then $X_1$$\cap$cl(A)$\subseteq$(gsp)*-ker(A). Now, cl(A)= X$\cap$cl(A)=($X_1$$\cup$$X_2$) $\cap$cl(A) = ($X_1$$\cap$cl(A)) $\cup$ ($X_2$$\cap$cl(A)) $\subseteq$(gsp)*-ker(A). Then by Theorem 2.6, A is (gsp)**-closed.

Theorem 4.15: Arbitrary intersection of (gsp)**-closed sets is (gsp)**-closed.

Proof: Let {A_i} be the collection of (gsp)**-closed sets of X. Let A=$\cap A_i$. Since A$\subseteq A_i$, for each i, then cl(A)$\subseteq$cl(A_i). That implies, $X_1$$\cap$cl(A)$\subseteq X_1$$\cap$cl($A_i$). Since each A_i is (gsp)**-closed, then by Theorem 4.14, $X_1$$\cap$cl($A_i$)$\subseteq A_i$, for each i. Now, $X_1$$\cap$cl(A)=$X_1$$\cap$cl($\cap A_i$)$\subseteq\cap$($X_1$$\cap$cl($A_i$))$\subseteq\cap A_i$=A. Again by Theorem 4.14, A is (gsp)**-closed.

Remark 4.16: The set of all (gsp)**- closed sets form a topology on X.

5. (gsp)** open sets

Definition 5.1.A subset A of (X, τ) is said be (gsp)**-open set if its complement X\A is (gsp)**-closed in X. The family of all (gsp)**-open sets in X is denoted by (gsp)**-O(X, τ).

Theorem 5.1: For a topological space (X,τ)

(i) Every open set is (gsp)** open set.
(ii) Every g* - open is (gsp)** open set.
(iii) Every (gsp)* open set is (gsp)** open set.
(iv) Every (gsp)** open set is gspr open set.
(v) Every (gsp)** open set is (g*p) open set.
(vi) Every (gsp)** open set is rwg open set.
(vii) Every (gsp)** open set is (αg) open set.
(viii) Every (gsp)** open set is gs open set.
(ix) Every (gsp)** open set is (gsp) open set.
(x) Every (gsp)** open set is gpr open set.
(xi) Every (gsp)** open set is wg open set.
(xii) Every (gsp)** open set is gp open set.
(xiii) (gsp)** open set is independent of sg** open sets.

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