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Fuzzy $\alpha\psi$-closed sets

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Abstract. In this paper, a new class of set called fuzzy $\alpha\psi$-closed set is introduced and its properties are studied. As an application of this set we also introduce the notions $F\alpha\psi$-continuity, $F\alpha\psi$-irresolute mappings and $F\alpha\psi$-connectedness and we establish some fundamental properties of these fuzzy mappings.

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1. Introduction

The concept of fuzzy set and fuzzy set operations were first introduced by Zadeh in his classical paper [11]. Subsequently several authors have applied various basic concepts from general topology to fuzzy sets and developed the theory of fuzzy topological spaces. Pu and Liu [7] introduced the concept of quasi-coincidence and quasi-neighbourhoods by which the extensions of functions in fuzzy settings can very interestingly and effectively be carried out.

The aim of this paper is to introduce the notion of fuzzy $\alpha\psi$-closed set in topological space. Moreover, as applications, we introduce $F\alpha\psi$-continuity, $F\alpha\psi$-irresolute mappings and $F\alpha\psi$-connectedness.

2. Preliminaries

Throughout this paper X means a fuzzy topological space (briefly, fts) in Chang's [3] sense. For a fuzzy set A of a fuzzy topological space X, the notion $cl(A)$, $int(A)$ and $1 - A$ denote the closure, the interior and the complement of A respectively. By 0_X and 1_X we will mean the fuzzy sets with constant membership function 0 (zero function) and 1 (unit function) respectively. The following definitions are useful in the sequel.

Definition 2.1. A fuzzy set A of a space (X, τ) is called

1. a fuzzy semi-open (breifly, Fs-open) set [1, 4] if $A \leq cl(int(A))$ and a fuzzy semi-closed(breifly, Fs-closed) set if $int(cl(A)) \leq A$.

2. a fuzzy α-open (breifly, $F\alpha$-open) set [2] if $A \leq int(cl(int(A)))$ and a fuzzy α-closed (breifly, $F\alpha$-closed) set if $cl(int(cl(A))) \leq A$.

3. a fuzzy pre-open (breifly, Fp-open) set [2] if $A \leq int(cl(A))$ and a fuzzy pre-closed (breifly, Fp-closed) set if $cl(int(A)) \leq A$.

4. a fuzzy semi pre-open (breifly, Fsp-open) set [10] if $A \leq cl(int(cl(A)))$ and a fuzzy semi pre-closed (breifly, Fsp-closed) set if $int(cl(int(A))) \leq A$. By $FSO(X, \tau)$(resp. $F\alpha O(X, \tau)$, $FPO(X, \tau)$, $FSPO(X, \tau)$,) we denote the family of all Fs-open (resp. $F\alpha$-open, Fp-open, Fsp-open) sets of fts X.

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

1. a Fuzzy generalized α-closed (briefly $Fg\alpha$-closed) set [9] if $\alpha cl(A) \leq H$ whenever $A \leq H$ and H is $F\alpha$-open in (X, τ). The complement of $Fg\alpha$-closed set is called $Fg\alpha$-open set.

2. a Fuzzy generalized pre-closed (briefly Fgp-closed) set [6] if $pcl(A) \leq H$ whenever $A \leq H$ and H is F-open in (X, τ). The complement of Fgp-closed set is called Fgp-open set.

3. a Fuzzy generalized semi-pre closed (briefly $Fgsp$-closed) set [8] if $spcl(A) \leq H$ whenever $A \leq H$ and H is fuzzy open in (X, τ). The complement of fuzzy gsp-closed set is called fuzzy gsp-open set.

4. a fuzzy semi-generalized closed (briefly Fsg-closed) set [5] if $scl(A) \leq H$ whenever $A \leq H$ and H is fuzzy semi-open in (X, τ). The complement of fuzzy sg-closed set is called fuzzy sg-open set.

5. a fuzzy ψ-closed (briefly $F\psi$-closed) set, if $scl(A) \leq H$ whenever $A \leq H$ and H is Fsg-open in (X, τ). The complement of fuzzy ψ-closed set is called fuzzy ψ-open set.

Definition 2.3 ([7])**.** A fuzzy point $x_p \in A$ is said to be quasi-coincident with the fuzzy set A denoted by $x_p q A$ if and only if $p + A(x) > 1$. A fuzzy set A is quasi-coincident with a fuzzy set B denoted by AqB if and only if there exists $x \in X$ such that $A(x)+B(x) > 1$. If A and B are not quasi-coincident then we write $A\overline{q}B$. Note that $A < B \Longleftrightarrow A\overline{q}(1 - B)$.

Definition 2.4 ([7])**.** A fuzzy topological space (X, τ) is said to be fuzzy semi-connected (briefly, Fs-connected) if and only if the only fuzzy sets which are both Fs-open and Fs-closed are 0_X and 1_X.

Definition 2.5 ([3])**.** Let f be a mapping from X into Y. If A is a fuzzy set of X and B is a fuzzy set of Y, then

(i) $f(A)$ is a fuzzy set of Y, where

$$\begin{aligned} f(A) &= sup_{x \in f^{-1}(y)}\ A(x),\ if\ f^{-1}(y) \neq 0 \\ &= 0, \text{ otherwise, for every } y \in Y \end{aligned}$$

(ii) $f^{-1}(B)$ is fuzzy set of X, where $f^{-1}(B)(x) = B(f(x))$ for each $x \in X$,
(iii) $f^{-1}(1 - B) = 1 - f^{-1}(B)$.

3. On fuzzy $\alpha\psi$-closed sets

Definition 3.1. A fuzzy $\alpha\psi$-closed (briefly, $F\alpha\psi$-closed) set if $\psi cl(A) \leq H$ whenever $A \leq H$ and H is $F\alpha$-open in (X, τ). The complement of fuzzy $\alpha\psi$-closed set is called fuzzy $\alpha\psi$-open set.

By $F\alpha\psi C(X, \tau)$, we denote the family of all fuzzy $\alpha\psi$-closed sets of fts X.

Theorem 3.2. *Every fuzzy-closed, $F\alpha$-closed, $Fg\alpha$-closed sets are $F\alpha\psi$-closed and every $F\alpha\psi$-closed set is Fs-closed, Fgp-closed and $Fgsp$-closed.*

Proof. It is Obvious. □

From the above discussion we introduce the following diagram

$$\begin{array}{ccccc} F-closed & & & & Fgp-closed \\ \downarrow & \searrow & & \nearrow & \\ F\alpha-closed & \longrightarrow & F\alpha\psi-closed & \longrightarrow & Fgsp-closed \\ \downarrow & \nearrow & & \searrow & \\ Fg\alpha-closed & & & & Fs-closed \end{array}$$

The converse of the above theorem is not true in general by the following necessary counter example.

Example 3.3. Let $X = \{a, b\}$ and $Y = \{x, y, z\}$ and fuzzy sets A, B, E, H, K, L be defined by:

A(a) = 0.1, A(b) = 0.2
B(a) = 0.2, B(b) = 0.4
K(a) = 0.1, K(b) = 0.2
L(a) = 0.3, L(b) = 0.7
E(x) = 0.1, E(y) = 0.2, E(z) = 0.7
H(x) = 0.1, H(y) = 0.4, H(z) = 0.7

Let $\tau = \{0, L, 1\}$, $\sigma = \{0, H, 1\}$ and $\gamma = \{0, E, 1\}$. Then A is $Fgsp$-closed in (Y, γ) but not $F\alpha\psi$-closed. B is $F\alpha\psi$-closed in (Y, σ) but not $F\alpha$-closed. K is $F\alpha\psi$-closed in (Y, σ) but not Fs-closed. E is $F\alpha\psi$-closed in (X, τ) but not $Fg\alpha$-closed.

Theorem 3.4. *Let (X, τ) be a fts and let $A \in I^X$. If A is $F\alpha\psi$-closed set and $A \leq B \leq \psi cl(A)$, then B is $F\alpha\psi$-closed set.*

Proof. Let H be a $F\alpha$-open set such that $B \leq H$. Since $A \leq B$, then $A \leq H$. But A is $\alpha\psi$-closed, so $\psi cl(A) \leq H$. Since $B \leq \psi cl(A)$. Since $\psi cl(B) \leq \psi cl(A)$ and hence $\psi cl(B) \leq H$. Therefore B is $F\alpha\psi$-closed set. □

Theorem 3.5. *Let A be $F\alpha\psi$-open in X and $\psi int(A) \leq B \leq A$, then B is $F\alpha\psi$-open.*

Proof. Suppose A is $F\alpha\psi$-open in X and $\psi int(A) \leq B \leq A$. Then $1 - A$ is $F\alpha\psi$-closed and $1 - A \leq 1 - B \leq \psi cl(1 - A)$. Then $1 - A$ is $F\alpha\psi$-closed set by theorem 3.4. Hence B is $F\alpha\psi$-open set in X. □

Theorem 3.6. *Let (X, τ) be a fts. A fuzzy set $A \in I^X$ is $F\alpha\psi$-open set if and only if $B \leq \psi int(A)$ whenever B is $F\alpha$-closed set and $B \leq A$.*

Proof. Let A be a $F\alpha\psi$-open set and let B be $F\alpha$-closed set such that $B \leq A$. Then $(1-A) \leq (1-B)$ and hence $\psi cl(1-A) \leq (1-B)$, since $(1-A)$ is $F\alpha\psi$-closed. But $\psi cl(1-A) = 1-(\psi int(A))$, thus $B \leq \psi int(A)$.

Conversely, suppose that the condition is satisfied, then $(1-(\psi int(A))) \leq (1-B)$ whenever $(1-B)$ is $F\alpha$-open set and $(1-A) \leq (1-B)$. This implies that $\psi cl(1-A) \leq (1-B) = H$ where H is $F\alpha$-open set and $(1-A) \leq H$. Therefore $(1-A)$ is $F\alpha\psi$-closed set and hence A is $F\alpha\psi$-open. □

Theorem 3.7. *A fuzzy set A of (X, τ) is $F\alpha\psi$-closed if and only if $A\overline{q}E$ implies $\psi cl(A)\overline{q}E$, for every $F\alpha$-closed set E of X.*

Proof. Let E be a $F\alpha$-closed set of X and $A\overline{q}E$. Then $A \leq (1-E)$ and $(1-E)$ is $F\alpha$-open in X, which implies that $\psi cl(A) \leq (1-E)$ as A is $F\alpha\psi$-closed. Hence $\psi cl(A)\overline{q}E$.

Conversely, let H be $F\alpha$-open set of X such that $A \leq H$. Then $A\overline{q}(1-H)$ and $(1-H)$ is $F\alpha$-closed in X. By hypothesis, $\psi cl(A)\overline{q}(1-H)$ implies $\psi cl(A) \leq H$. Hence A is $F\alpha\psi$-closed in X. □

Theorem 3.8. *Let A be $F\alpha\psi$-closed set of (X, τ) and x_p be a fuzzy point of X such that $x_p\overline{q}\psi cl(A)$ then $\psi cl(x_p)qA$.*

Proof. If $\psi cl(x_p)\overline{q}A$ then $A \leq 1-\psi cl(x_p)$ and so $\psi cl(A) \leq 1-\psi cl(x_p) \leq 1-x_p$ because $1-\psi cl(x_p)$ is $F\alpha$-open and A is $F\alpha\psi$-closed in X. Hence $x_p\overline{q}\psi cl(A)$ is a contradiction. □

4. On fuzzy $\alpha\psi$-continuous and fuzzy $\alpha\psi$-irresolute mappings

Definition 4.1. A functin $f : (X, \tau) \rightarrow (Y, \sigma)$ is called a fuzzy $\alpha\psi$-continuous (briefly, $F\alpha\psi$-continuous) if $f^{-1}(V)$ is $F\alpha\psi$-closed in (X, τ) for every fuzzy closed set V of (Y, σ).

Theorem 4.2. *Let $f : (X, \tau) \rightarrow (Y, \sigma)$ be a function from a fts (X, τ) into a fts (Y, σ). Then the following statements are equivalent.*

(i) *f is $\alpha\psi$-continuous;*

(ii) *the inverse image of each open fuzzy set in Y is $F\alpha\psi$-open set in X.*

Proof. It is obvious, because $f^{-1}(1-H) = 1-f^{-1}(H)$ for each fuzzy open set H of Y. □

Theorem 4.3. *For $F\alpha\psi$-continuous mapping $f : (X, \tau) \rightarrow (Y, \sigma)$, the following statements hold:*

(i) *$f(\alpha\psi cl(A)) \leq cl(f(A))$, for every fuzzy set A in X;*

(ii) *$\alpha\psi cl(f^{-1}(B)) \leq f^{-1}(cl(B))$, for every fuzzy set B in Y.*

Proof. (i) Since $cl(f(A))$ is fuzzy closed set in Y and f is $F\alpha\psi$-continuous, then $f^{-1}(cl(f(A)))$ is $\alpha\psi$-closed in X. Now, since $A \leq f^{-1}(cl(f(A)))$. So, $\alpha\psi cl(A) \leq f^{-1}(cl(f(A)))$. Therefore, $f(\alpha\psi cl(A)) \leq cl(f(A))$.

(ii) Replacing A by B in (i), we get $f(\alpha\psi cl(f^{-1}(B))) \leq cl(f(f^{-1}(B))) \leq cl(B)$. Hence $\alpha\psi cl(f^{-1}(B)) \leq f^{-1}(cl(B))$. □

Definition 4.4. A functin $f : (X, \tau) \to (Y, \sigma)$ is called a fuzzy $\alpha\psi$-irresolute (briefly, $F\alpha\psi$-irresolute) if $f^{-1}(V)$ is $F\alpha\psi$-closed in (X, τ) for every $F\alpha\psi$-closed set V of (Y, σ).

Theorem 4.5. *Every $F\alpha\psi$-irresolute map is $F\alpha\psi$-continuous.*

Proof. Since every closed fuzzy set is $\alpha\psi$ closed, then it is proved that f is $F\alpha\psi$-continuous. The converse of the above theorem need not be true in general by the following example. □

Example 4.6. Let $X = \{a, b\}$, $Y = \{x, y\}$. The fuzzy set A is defined as: $A(a) = 0.3$ and $A(b) = 0.7$. Let $\tau = \{0, A, 1\}$ and $\sigma = \{0, 1\}$. Then the mapping $f : (X, \tau) \to (Y, \sigma)$ is defined by $f(a) = x$ and $f(b) = y$ is $F\alpha\psi$-continuous but not $F\alpha\psi$-irresolute

Theorem 4.7. *If $f : (X, \tau) \to (Y, \sigma)$ is $F\alpha\psi$-continuous then for each fuzzy point x_p of X and each $A \in \sigma$ such that $f(x_p) \in A$, there exists a $F\alpha\psi$-open set B of X such that $x_p \in B$ and $f(B) \leq A$.*

Proof. Let x_p be fuzzy point of X and $A \in \sigma$ such that $f(x_p) \in A$. Put $B = f^{-1}(A)$. Then by hypothesis B is a $F\alpha\psi$-open set of X such that $x_p \in B$ and $f(B) = f(f^{-1}(A)) \leq A$. □

Theorem 4.8. *Let $f : (X, \tau) \to (Y, \sigma)$ be $F\alpha\psi$-continuous, then for each fuzzy point x_p of X and each $A \in \sigma$ such that $f(x_p)qA$, there exists a $F\alpha\psi$-open set B of X such that x_pqB and $f(B) \leq A$.*

Proof. Let $x_p \in X$ and $A \in \sigma$ such that $f(x_p)qA$. Put $B = f^{-1}(A)$. Then by hypothesis B is a $F\alpha\psi$-open set of X such that x_pqB and $f(B) = f(f^{-1}(A)) \leq A$. □

Theorem 4.9. *Let $f : (X, \tau) \to (Y, \sigma)$ and $g : (Y, \sigma) \to (Z, \eta)$ be any two functions, then*

(i) *$gof : (X, \tau) \to (Z, \eta)$ is $F\alpha\psi$-continuous, if g is fuzzy continuous and f is $F\alpha\psi$-continuous.*

(ii) *gof is $F\alpha\psi$-continuous, if g is $F\alpha\psi$-continuous and f is $F\alpha\psi$-irresolute.*

Proof. It is Obvious □

Theorem 4.10. *If $f : (X, \tau) \to (Y, \sigma)$ and $g : (Y, \sigma) \to (Z, \eta)$ are both $F\alpha\psi$-irresolute mappings, then $gof : (X, \tau) \to (Z, \eta)$ is $F\alpha\psi$-irresolute.*

Proof. Suppose that H is $F\alpha\psi$-open set in Z, then $g^{-1}(H)$ is $F\alpha\psi$-open in Y and $f^{-1}(g^{-1}(H))$ is $F\alpha\psi$-open in X, since g and f are $F\alpha\psi$-irresolute. Thus, $(gof)^{-1}(H) = f^{-1}(g^{-1}(H))$ is $F\alpha\psi$-open and therefore gof is $F\alpha\psi$-irresolute. □

Theorem 4.11. *If $f : (X, \tau) \to (Y, \sigma)$ be a mapping from a fts (X, τ) into a fts (Y, σ), then the following statements are equivalent:*

(i) *f is $F\alpha\psi$-irresolute;*

(ii) *the inverse image of each $F\alpha\psi$-open set in Y is $F\alpha\psi$-open set in X.*

Proof. It is Obvious □

5. Fuzzy $\alpha\psi$-connectedness

Definition 5.1. A fuzzy topological space (X, τ) is said to be fuzzy $\alpha\psi$-connected (briefly, $F\alpha\psi$-connected) if and only if the only fuzzy sets which are both $F\alpha\psi$-open and $F\alpha\psi$-closed are 0_X and 1_X.

Example 5.2. Let $X = \{a, b, c\}$ and a fuzzy topology $\tau = \{0, 1, A\}$, where $A : X \to [0, 1]$ is such that $A(a) = 1$, $A(b) = A(c) = 0$. Then it is clear that (X, τ) is $F\alpha\psi$-connected.

Theorem 5.3. *A fuzzy topological space (X, τ) is $F\alpha\psi$-connected if and only if X has no non zero $F\alpha\psi$-open sets A and B such that $A + B = 1_X$.*

Proof. Suppose (X, τ) is $F\alpha\psi$-connected. If X has two non zero $F\alpha\psi$-open sets A and B such that $A + B = 1_X$, then A is proper $F\alpha\psi$-open and $F\alpha\psi$-closed set of X. Hence, X is not $F\alpha\psi$-connected, which is a contradiction.

Conversely, If (X, τ) is not $F\alpha\psi$-connected, then it has a proper fuzzy set A of$X$ which is both $F\alpha\psi$-open and $F\alpha\psi$-closed. So $B = 1 - A$, is a $F\alpha\psi$-open set of X such that $A + B = 1_X$, which is a contradiction. □

Theorem 5.4. *If $f : (X, \tau) \to (Y, \sigma)$ is $F\alpha\psi$-continuous surjective and (X, τ) is $F\alpha\psi$-connected, then (Y, σ) is fuzzy connected.*

Proof. Let X be a $F\alpha\psi$-connected and Y is not fuzzy connected. As Y is not fuzzy connected, then there exists a proper fuzzy set V of Y such that $V \neq 0_Y$, $V \neq 1_Y$ and V is both *fuzzy open* and *fuzzy closed* set. Since, f is $F\alpha\psi$-continuous, $f^{-1}(V)$ is both $F\alpha\psi$-open and $F\alpha\psi$-closed set of X such that $f^{-1}(V) \neq 0_X$ and $f^{-1}(V) \neq 1_X$. Hence, X is not $F\alpha\psi$-connected, which is a contradiction. □

Theorem 5.5. *If $f : (X, \tau) \to (Y, \sigma)$ is $F\alpha\psi$-irresolute surjective and (X, τ) is $F\alpha\psi$-connected, then (Y, σ) is so.*

Proof. Similar to the proof of the above theorem. □

Definition 5.6. A fuzzy topological space (X, τ) is said to be $F\alpha\psi$-connected between fuzzy sets A and B if there is no $F\alpha\psi$-closed, $F\alpha\psi$-open set E in X such that $A \leq E$ and $E\overline{q}B$.

Theorem 5.7. *If a fuzzy topological space (X, τ) is said to be $F\alpha\psi$-connected between fuzzy sets A and B if and only if there is no $F\alpha\psi$-closed, $F\alpha\psi$-open set E in X such that $A \leq E \leq 1 - B$.*

Proof. It is Obvious. □

Theorem 5.8. *If a fuzzy topological space (X, τ) is said to be $F\alpha\psi$-connected between fuzzy sets A and B, then A and B are non zero.*

Proof. If $A = 0$, then A is $F\alpha\psi$-closed, $F\alpha\psi$-open in X such that $A \leq A$ and $A\overline{q}B$. Hence X cannot be $F\alpha\psi$-connected, which is a contradiction. □

Theorem 5.9. *If a fuzzy topological space (X, τ) is $F\alpha\psi$-connected between fuzzy sets A and B and $A \leq A_1$ and $B \leq B_1$, then (X, τ) is $F\alpha\psi$-connected between fuzzy sets A_1 and B_1.*

Proof. Suppose (X, τ) is not $F\alpha\psi$-connected between A_1 and B_1. Then, there is a $F\alpha\psi$-closed, $F\alpha\psi$-open set E in X such that $A_1 \leq E$ and $E\overline{q}B_1$. Clearly, $A \leq E$. Now we claimb that $E\overline{q}B$. If EqB, then there exists a point $x \in X$ such that $E(x) + B(x) > 1$. Therefore, $E(x) + B_1(x) > E(x) + B(x) > 1$ and EqB_1, which is a contradiction. □

Theorem 5.10. *Let (X, τ) be a fuzzy topological space, A and B are fuzzy sets in X. If AqB, then (X, τ) is $F\alpha\psi$-connected between A and B.*

Proof. If E is any $F\alpha\psi$-closed, $F\alpha\psi$-open set in X such that $A \leq E$, then AqB implies EqB. Converse of the above theorem need not be true by the following example. □

Example 5.11. Let $X = \{a, b\}$. Fuzzy sets A, B and H on X are defined as:

$$A(a) = 0.3,\ A(b) = 0.5;$$
$$B(a) = 0.4,\ B(b) = 0.5;$$
$$H(a) = 0.5,\ H(b) = 0.7.$$

Let $I = \{0, H, 1\}$ be fuzzy topology on X. Then (X, τ) is $F\alpha\psi$-connected between A and B but $A\overline{q}B$.

Theorem 5.12. *A fuzzy topological space (X, τ) is $F\alpha\psi$-connected if and only if it is $F\alpha\psi$-connected between every pair of its non zero fuzzy sets.*

Proof. Let A and B be any pair of non zero fuzzy sets X. Suppose (X, τ) is not $F\alpha\psi$-connected between A and B. Then there is a $F\alpha\psi$-closed, $F\alpha\psi$-open set E in X such that $A \leq E$ and $E\overline{q}B$. Since A and B are non zero, it follows that E is proper $F\alpha\psi$-closed, $F\alpha\psi$-open set of X. This implies that is not $F\alpha\psi$-connected.

Conversely, if suppose (X, τ) is not $F\alpha\psi$-connected. Then there exists a proper fuzzy set E of X which is both $F\alpha\psi$-closed and $F\alpha\psi$-open. Consequently, X is not $F\alpha\psi$-connected between E and $1 - E$, which is a contradiction. □

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