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STRONG FUZZY BI-IDEALS OF BCK-ALGEBRAS

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ABSTRACT. We consider the strong fuzzification of the concept of sub-algebras and strong Bi-ideals in BCK - algebras are defined and explored some of their properties. We also fuzzify the notion of equivalence relations on the family of all strong fuzzy Bi-ideals of a BCK-algebras are discussed and some of the properties are investigated.

1. INTRODUCTION

After the initiation of the concept of fuzzy set by Zadeh in [5], Imaiand Iseki introduced two classes of abstract algebras, BCK-algebras and BCI-algebras. BCK-algebras where studied by many researches.

In this paper, using the Atanassov, [1], and Young Bae Jun, [2] we establish the notion of equivalence relations on the family of all strong fuzzification of the concept of sub-algebras and strong fuzzy Bi-ideals of a BCK-algebra and investigate some of the properties.

2. PRELIMINARIES

The following definition is given in [3].

Definition 2.1. *A BCK-algebra is a non-empty set X with a binary operation $*$ and a constant 0 satisfying the following condition:*

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(a) $((x*y)*(x*z)*(z*y))=0$;
(b) $(x*(x*y))*y)=0$;
(c) $x*x=0$;
(d) $0*x=0$;
(e) $x*y=0$ *and* $y*x=0$ *imply that* $x=y$ *for all* $x,y,z\in X$.

The following definition is given in [5].

Definition 2.2. *A partial ordering "$\leq$" on X can be defined by $x\leq y$ iff $x*y=0$.*

The following definition is given in [3].

Definition 2.3. *A non-empty subset S of a BCK-algebra X is called a sub-algebra of X if $x*y\in S$ whenever $x,y\in S$.*

The next definition is given in [1].

Definition 2.4. *A non-empty subset I of a BCK-algebra X is called an ideal of X if*

(a) $0\in I$;
(b) $x*y\in I$ *and* $y\in I$ *imply that* $x\in I$ *for all* $x,y\in X$.

The following two definitions are given in [5].

Definition 2.5. *A fuzzy set α in a non-empty set X we mean a function* $\alpha:X\to[0,1]$.

Definition 2.6. *The complement of α, denoted by $\bar{\alpha}$ is the fuzzy set in X given by $\bar{\alpha}(x)=1-\alpha(x)$ for all $x\in X$.*

A fuzzy set α in a BCK-algebra X is called a strong fuzzy sub-algebra of X if $\alpha(y*z)\geq min\{\alpha(y),\alpha(z)\}$ for all $y,z\in Y$.

In [2] is given the next definition.

Definition 2.7. *A fuzzy set μ in a BCK-algebra X is called a fuzzy ideal of X if*

(a) $\alpha(0)\geq\alpha(x)$ *for all* $x\in X$.
(b) $\alpha(x)\geq min\{\alpha(x*y),\alpha(y)\}$ *for all* $x,y\in X$.

In [3] are given the following definitions:

Definition 2.8. *For any $t\in[0,1]$ and a fuzzy set α in a non-empty set X, the set $U(\alpha;t)=\{x\in X/\alpha(x)\geq t\}$ is called an upper t-level cut of α and the set $L(\alpha;t)=\{x\in X/\alpha(x)\leq t\}$ is called a lower t-level cut of α.*

Definition 2.9. *A mapping $f : Y \to Z$ of BCK-algebras is called a homomorphism if $f(y * z) = f(y) * f(z)$ for all $y, z \in Y$.*

Note that if $f : Y \to Z$ is a homomorphism of BCK-algebras then $f(0) = 0$.

Let $f : Y \to Z$ be a homomorphism of BCK-algebras. For any SFS $A = (\alpha_A, \beta_A)$ in Z, we define a new SFS $A^f = (\alpha_A^f, \beta_A^f)$ in Y by, $\alpha_A^f(x) = \alpha_A(f(x))$, $\beta_A^f(x) = \beta_A(f(x))$ for all $y \in Y$.

In [1] is given the definition:

Definition 2.10. *A non-empty set X is an object having the form*

$$A = \{(x, \alpha_A(x), \beta_A(x))/x \in X\}$$

where the functions $\alpha : X \to [0,1]$ and $\beta : X \to [0,1]$ denote the degree of membership and the degree of non-membership of each element $x \in X$ to the set A and $0 \leq \alpha_A(x) + \beta_A(x) \leq 1$ for all $x \in X$.

An intuitionistic fuzzy set $A = \{(x, \alpha_A(x), \beta_A(x))/x \in X\}$ in X can be identified to an ordered pair (α_A, β_A) in $I^X \times I^X$. For the sake of simplicity, we use the symbol $A = (\alpha_A, \beta_A)$ for the IFS, $A = \{(x, \alpha_A(x), \beta_A(x)/x \in X\}$.

In [4] is given the following definition.

Definition 2.11. *A fuzzy subset β in a BCK-algebra X is called fuzzy Bi-ideal if*

(a) $\beta_A(0) \geq \beta_A(x)$.
(b) $\beta_A(x * y) \geq min\{\beta_A(x * y * z), \beta_A(z)\}$ *for all* $x, y, z \in X$.

In [1] is given the following definition.

Definition 2.12. *An Intuitionistic fuzzy set $A = (\alpha_A, \beta_A)$ in X is called an intuitionistic fuzzy sub-algebra of X if it satisfies:*

(a) $\alpha_A(x * y) \geq min\{\alpha_A(x), \alpha_A(y)\}$.
(b) $\beta_A(x * y) \leq max\{\beta_A(x), \beta_A(y)\}$ *for all* $x, y \in X$.

Proposition 2.1. *Every intuitionistic fuzzy sub-algebra $A = (\alpha_A, \beta_A)$ of X satisfies the inequalities*

(a) $\alpha_A(0) \geq \alpha_A(x)$ *and*
(b) $\beta_A(0) \leq \beta_A(x)$ *for all* $x \in X$.

In [3] is given the following definition.

Definition 2.13. *An Intuitionistic fuzzy set $A = (\alpha_A, \beta_A)$ in X is called an intuitionistic fuzzy ideal of X if it satisfies the following inequalities:*

(a) $\alpha_A(0) \geq \alpha_A(x)$ *and* $\beta_A(0) \leq \beta_A(x)$,
(b) $\alpha_A(x) \geq min\{\alpha_A(x * y), \alpha_A(y)\}$,
(c) $\beta_A(x) \leq max\{\beta_A(x * y), \beta_A(y)\}$ *for all* $x, y \in X$.

In [4] is given the following definition.

Definition 2.14. *An intuitionistic fuzzy set $A = (\alpha_A, \beta_A)$ in X is called an intuitionistic fuzzy Bi-ideal of X if it satisfies:*

(a) $\alpha_A(0) \geq \alpha_A(x)$ *and* $\beta_A(0) \leq \beta_A(x)$.
(b) $\alpha_A(x * y) \geq min\{\alpha_A(x * y * z), \alpha_A(z)\}$
(c) $\beta_A(x * y) \leq max\{\beta_A(x * y * z), \beta_A(z)\}$ *for all* $x, y, z \in X$.

3. STRONG FUZZY BI-IDEAL

Definition 3.1. *A Strong fuzzy set $A = (\alpha_A, \beta_A)$ in X is called a Strong fuzzy Bi-ideal of X if it satisfies:*

(a) $\alpha_A(0) \geq \alpha_A(x)$ *and* $\beta_A(0) \leq \beta_A(x)$.
(b) $\alpha_A(y * z) \geq min\{\alpha_A((z * (y * z)) * x), \alpha_A(x)\}$.
(c) $\beta_A(y * z) \leq max\{\beta_A((z * (y * z)) * x), \beta_A(x)\}$ *for all* $x, y, z \in X$.

Example 1. *Consider a BCK-algebra $X = \{0, a, b, c\}$ with the following cayley table.*

$*$	0	a	b	c
0	0	0	0	0
a	a	0	0	a
b	b	a	0	b
c	c	c	c	0

Define an SFS, $A = (\alpha_A, \beta_A)$ in X as follows :
$\alpha_A(0) = 0.6$, $\alpha_A(a) = 0.5$, $\alpha_A(b) = 0.8$, $\alpha_A(c) = 0.3$
$\beta_A(0) = 0.1$, $\beta_A(a) = 0.8$, $\beta_A(b) = 0.4$, $\beta_A(c) = 0.6$.
Then $A = (\alpha_A, \beta_A)$ is a Strong fuzzy Bi-ideal of X.

Lemma 3.1. *Let a SFS $A = (\alpha_A, \beta_A)$ in X be a Strong fuzzy Bi-ideal of X. If the inequality $y * z \leq x$ holds in X, then*

(a) $\alpha_A(y * z) \geq min\{\alpha_A(y), \alpha_A(x)\}$,
(b) $\beta_A(y * z) \leq max\{\beta_A(y), \beta_A(x)\}$.

Proof. Let $x, y, z \in X$ be such that $y * z \leq x$. Then $(z * (y * z)) = y$. Now

$$\begin{aligned} (a) \quad \alpha_A(y * z) &\geq min\{\alpha_A((z * (y * z)) * x), \alpha_A(x)\} \\ &\geq min\{min\{\alpha_A(y), \alpha_A(x)\}, \alpha_A(x)\} \\ &= min\{\alpha_A(y), \alpha_A(x)\} \end{aligned}$$

Therefore, $\alpha_A(y * z) \geq min\{\alpha_A(y), \alpha_A(x)\}$

$$\begin{aligned} (b) \quad \beta_A(y * z) &\leq max\{\beta_A((z * (y * z)) * x), \beta_A(x)\} \\ &\leq max\{max\{\beta_A(y), \beta_A(x)\}, \beta_A(x)\} \\ &= max\{\beta_A(y), \beta_A(x)\} \end{aligned}$$

Therefore, $\beta_A(y * z) \leq max\{\beta_A(y), \beta_A(x)\}$.
This completes the proof. □

Lemma 3.2. *Let $A = (\alpha_A, \beta_A)$ be a Strong fuzzy Bi-ideal of X. If $y * z \leq y$ in X, then $\alpha_A(y * z) \geq \alpha_A(y)$, $\beta_A(y * z) \leq \beta_A(y)$ that is α_A is order-reserving and β_A is order-preserving.*

Proof. Let $x, y, z \in X$ be such that $y * z \leq y$.

$$\begin{aligned} (a) \quad \alpha_A(y * z) &\geq min\{\alpha_A((z * (y * z)) * x), \alpha_A(x)\} \\ &\geq min\{min\{\alpha_A(y), \alpha_A(x)\}, \alpha_A(x)\} \\ &= min\{\alpha_A(y), \alpha_A(x)\} \\ &\geq min\{\alpha_A(y), \alpha_A(0)\} \\ &= \alpha_A(y) \end{aligned}$$

Therefore, $\alpha_A(y * z) \geq \alpha_A(y)$.

$$\begin{aligned} (b) \quad \beta_A(y * z) &\leq max\{\beta_A((z * (y * z)) * x), \beta_A(x)\} \\ &\leq max\{max\{\beta_A(y), \beta_A(x)\}, \beta_A(x)\} \\ &= max\{\beta_A(y), \beta_A(x)\} \\ &\leq max\{\beta_A(y), \beta_A(0)\} \\ &= \beta_A(y) \end{aligned}$$

Therefore, $\beta_A(y * z) \leq \beta_A(y)$.

Hence α_A is order-reserving and β_A is order-preserving. □

Theorem 3.1. *If* $A = (\alpha_A, \beta_A)$ *is a Strong fuzzy Bi-ideal of* X*, then for any* $y * z, a_1, a_2, ..., a_n \in X, (...((y * z * a_1) * a_2) * ...) * a_n = 0$ *implies* $\alpha_A(x) \geq min\{\alpha_A(a_1), \alpha_A(a_2), ..., \alpha_A(a_n)\}$ *and* $\beta_A(x) \leq max\{\beta_A(a_1), \beta_A(a_2), ..., \beta_A(a_n)\}$.

Proof. Using induction on n, the proof is straightforward. □

Theorem 3.2. *Every Strong fuzzy Bi-ideal of* X *is a Strong fuzzy sub-algebra of* X.

Proof. Let $A = (\alpha_A, \beta_A)$ be a Strong fuzzy bi-ideal of X.

Since $y * z \leq x$ for all $x, y, z \in X$, it follows from Lemma 3.2 that, $\alpha_A(y * z) \geq \alpha_A(x)$, $\beta_A(y * z) \leq \beta_A(x)$. Now,

$$\begin{array}{rrcl} (a) & \alpha_A(y * z) & \geq & \alpha_A(x) \\ & & \geq & min\{\alpha_A(y * z), \alpha_A(z)\} \\ & & \geq & min\{\alpha_A(x), \alpha_A(z)\} \end{array}$$

Therefore, $\alpha_A(y * z) \geq min\{\alpha_A(x), \alpha_A(z)\}$

$$\begin{array}{rrcl} (b) & \beta_A(y * z) & \leq & max\{\beta_A(y * z), \beta_A(z)\} \\ & & \leq & max\{\beta_A(x), \beta_A(z)\} \end{array}$$

Therefore, $\beta_A(y * z) \leq max\{\beta_A(x), \beta_A(z)\}$

Thus $A = (\alpha_A, \beta_A)$ is a Strong fuzzy sub-algebra of X. □

Theorem 3.3. *Let* $A = (\alpha_A, \beta_A)$ *be a Strong fuzzy sub-algebra of* X *such that* $\alpha_A(x) \geq min\{\alpha_A(y), \alpha_A(z)\}$, $\beta_A(x) \leq max\{\beta_A(y), \beta_A(z)\}$ *for all* $x, y, z \in X$ *satisfying the inequality* $y * z \leq y$*. Then* $A = (\alpha_A, \beta_A)$ *is a Strong fuzzy Bi-ideal of* X.

Proof. Let $A = (\alpha_A, \beta_A)$ be a Strong fuzzy sub-algebra of X. Recall that $V(0) \geq min\alpha_A(y * z)$ and $\beta_A(0) \leq max\beta_A(y * z)$ for all X.

Since $(z * z) * (z * x) \leq x$, it follows from the hypothesis that,

(a) $\alpha_A(y * z) \geq min\{\alpha_A((z * (y * z)) * x), \alpha_A(x)\}$

(b) $\beta_A(y * z) \leq max\{\beta_A((z(*y * z)) * x), \beta_A(x)\}$.

Hence $A = (\alpha_A, \beta_A)$ is a Strong fuzzy bi-ideal of X. □

Lemma 3.3. *A SFS* $A = (\alpha_A, \beta_A)$ *is a Strong fuzzy Bi-ideal of* X *iff the fuzzy sets* α_A *and* $\bar{\beta_A}$ *are fuzzy Bi-ideals of* X.

Proof. Let $A = (\alpha_A, \beta_A)$ be a Strong fuzzy bi-ideal of X.

For every $x, y, z \in X$, we have,

$$\begin{aligned} (a) \quad \bar{\beta_A}(0) &= 1 - \beta_A(0) \\ &\geq 1 - \beta_A(y * z) \\ &= \bar{\beta_A}(y * z) \end{aligned}$$

Therefore, $\bar{\beta_A}(0) \geq \bar{\beta_A}(y * z)$

$$\begin{aligned} (b) \quad \bar{\beta_A}(y * z) &= 1 - \beta_A(y * z) \\ &\geq 1 - max\{\beta_A((z(*y * z)) * x), \beta_A(x)\} \\ &= min\{1 - \beta_A((z * (y * z)) * x), 1 - \beta_A(x)\} \end{aligned}$$

Therefore, $\bar{\beta_A}(y * z) = min\{\bar{\beta_A}((z * (y * z)) * x), \bar{\beta_A}(x)\}$.

Hence $\bar{\beta_A}$ is a fuzzy bi-ideal of X.

Conversely assume that α_A and $\bar{\beta_A}$ are fuzzy bi-ideals of X.

For every $x, y, z \in X$, we have,

$\alpha_A(0) \geq \alpha_A(y * z)$, $1 - \beta_A(0) = \bar{\beta_A}(0) \geq \bar{\beta_A}(y * z) = 1 - \beta_A(y * z)$

That is, $\beta_A(0) \leq (y * z); \beta_A(y * z) \geq min\{\beta_A((z(*y * z)) * x, \beta_A(x)\}$ and

$$\begin{aligned} 1 - \beta_A(y * z) = \bar{\beta_A}(y * z) &\geq min\{\bar{\beta_A}((z * (y * z)) * x), \bar{\beta_A}(x)\} \\ &= min\{1 - \beta_A((z * (y * z)) * x), 1 - \beta_A(x)\} \\ &= 1 - max\{\beta_A((z * (y * z)) * x), \beta_A(x)\} \\ \beta_A(y * z) &\leq max\{\beta_A((z * (y * z)) * x), \beta_A(x)\} \end{aligned}$$

Hence $A = (\alpha_A, \beta_A)$ is a Strong fuzzy Bi-ideal of X. □

Theorem 3.4. *Let $A = (\alpha_A, \beta_A)$ is a Strong fuzzy set in X. Then $A = (\alpha_A, \beta_A)$ is a Strong fuzzy Bi-ideal of X iff $A = (\alpha_A, \bar{\alpha_A})$ and $A = (\beta_A, \bar{\beta_A})$ are Strong fuzzy Bi-ideals of X.*

Proof. If $A = (\alpha_A, \beta_A)$ is a Strong fuzzy bi-ideal of X, then $\alpha_A = \bar{\bar{\alpha_A}}$ and β_A are strong fuzzy Bi-ideals of X.

Hence $A = (\alpha_A, \bar{\alpha_A})$ and $A = (\beta_A, \bar{\beta_A})$ are Strong fuzzy Bi-ideals of X.

Conversely, if $A = (\alpha_A, \bar{\alpha_A})$ and $A = (\beta_A, \bar{\beta_A})$ are Strong fuzzy Bi-ideals of X, then the fuzzy sets α_A and $\bar{\beta_A}$ are Strong fuzzy Bi-ideals of X.

Hence $A = (\alpha_A, \beta_A)$ is a Strong fuzzy Bi-ideal of X. □

Theorem 3.5. *Let $f : Y \to Z$ be a homomorphism of BCK-algebra. If a SFS $A = (\alpha_A, \beta_A)$ in Z is a Strong fuzzy Bi-ideal of Z, then a SFS $A^f = (\alpha_A^f, \beta_A^f)$ in Y is a Strong fuzzy Bi-ideal of Y.*

Proof. We first have that

$$(a) \quad \alpha_A^f(y*z) = \alpha_A(f(y*z)) \leq \alpha_A(0) = \alpha_A(f(0))$$

Therefore, $\alpha_A^f(y*z) = \alpha_A^f(0)$.

$$(b) \quad \beta_A^f(y*z) = \beta_A(f(y*z)) \geq \beta_A(0) = \beta_A(f(0))$$

Therefore, $\beta_A^f(y*z) = \beta_A^f(0)$ for all $y*z \in Y$.
Let $x, y, z \in Y$. Then
(a)

$$\begin{aligned}
& min\{\alpha_A^f((z*(y*z))*x), \alpha_A^f(x)\} \\
= & min\{\alpha_A(f((z*(y*z))*x), \alpha_A(f(x)))\} \\
= & min\{\alpha_A(f((z*(y*z))*x), \alpha_A(f(x)))\} \\
\leq & min\{\alpha_A(f(z)*f(y*z)*f(x)), \alpha_A(f(x))\} \\
= & min\{\alpha_A(f(z)*f(y*z)*\alpha_A f(x)), \alpha_A(f(x))\} \\
\leq & min\{\alpha_A(f(y*z))\} \\
= & \alpha_A^f(y*z)
\end{aligned}$$

Therefore, $min\{\alpha_A^f((z*(y*z))*x), \alpha_A^f(x)\} \leq \alpha_A^f(y*z)$
(b)

$$\begin{aligned}
& max\{\beta_A^f((z*(y*z))*x), \beta_A^f(x)\} \\
= & max\{\beta_A(f((z*(y*z))*x), \beta_A(f(x)))\} \\
= & max\{\beta_A(f((z*(y*z))*x), \beta_A(f(x)))\} \\
\geq & max\{\beta_A(f(z)*f(y*z)*f(x)), \beta_A(f(x))\} \\
= & max\{\beta_A(f(z)*f(y*z)*\beta_A f(x)), \beta_A(f(x))\} \\
\leq & max\{\beta_A(f(y*z))\} \\
= & \beta_A^f(y*z)
\end{aligned}$$

Therefore, $max\{\beta_A^F((z*(y*z))*x), \beta_A^f(x)\} \geq \beta_A^f(y*z)$.
Hence $A^f = (\alpha_A^f, \beta_A^f)$ in Y is a Strong fuzzy Bi-ideal of Y. □

Theorem 3.6. *Let $f: Y \to Z$ be an epimorphism of BCK-algebras and let $A = (\alpha_A, \beta_A)$ be a SFS in Z. If $A^f = (\alpha_A^f, \beta_A^f)$ is a Strong fuzzy Bi-ideal of Y, then $A = (\alpha_A, \beta_A)$ is a Strong fuzzy Bi-ideal of Z.*

Proof. For any $y, z \in Z$, there exists $a \in Y$ such that $f(a) = y * z$. Then

$$\begin{aligned}(a) \quad \alpha_A(y*z) = \alpha_A(f(a)) = \alpha_A^f(a) &\leq \alpha_A^f(0)\\ &= \alpha_A(f(0))\\ &= \alpha_A(0)\end{aligned}$$

Therefore, $\alpha_A(y*z) = \alpha_A(0)$.

$$\begin{aligned}(b) \quad \beta_A(y*z) = \beta_A(f(a)) = \beta_A^f(a) &\geq \beta_A^f(0)\\ &= \beta_A(f(0))\\ &= \beta_A(0)\end{aligned}$$

Therefore, $\beta_A(y*z) = \beta_A(0)$.
Let $x, y, z \in Z$, then $f(a) = x$, $f(b) = y$ and $f(c) = z$ for some $a, b, c \in Y$. It follows that

$$\begin{aligned}(a)\alpha_A(y*z) &= \alpha_A(f(b)*f(c)) = \alpha_A^f(b*c)\\ &\geq min\{\alpha_A^f((c*(b*c))*a), \alpha_A^f(a)\}\\ &= min\{\alpha_A((f(c)*(b*c))*f(a)), \alpha_A(f(a))\}\\ &= min\{\alpha_A(f(c)*f(b)*f(a)), \alpha_A(f(a))\}\end{aligned}$$

Therefore, $\alpha_A(y*z) \geq min\{\alpha_A((z*(y*z))*x), \alpha_A(x)\}$

$$\begin{aligned}(b)\ \beta_A(y*z) &= \beta_A(f(b)*f(c)) = \beta_A^f(b*c)\\ &\leq max\{\beta_A^f((c*(b*c))*a), \beta_A^f(a)\}\\ &= max\{\beta_A((f(c)*(b*c))*f(a)), \beta_A(f(a))\}\\ &= max\{\beta_A(f(c)*f(b)*f(a)), \beta_A(f(a))\}\end{aligned}$$

Therefore, $\beta_A(y*z) \leq max\{\beta_A((z*(y*z))*x), \beta_A(x)\}$.
Hence $A = (\alpha_A, \beta_A)$ is a Strong fuzzy Bi-ideal of Z. □

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