

Some results on Interval-valued fuzzy BG -algebras

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Abstract- In this note the notion of interval-valued fuzzy BG -algebras (briefly, i-v fuzzy BG -algebras), the level and strong level BG -subalgebra is introduced. Then we state and prove some theorems which determine the relationship between these notions and BG -subalgebras. The images and inverse images of i-v fuzzy BG -subalgebras are defined, and how the homomorphic images and inverse images of i-v fuzzy BG -subalgebra becomes i-v fuzzy BG -algebras are studied.

Keywords- BG -algebra, fuzzy BG -subalgebra, interval-valued fuzzy set, interval-valued fuzzy BG -subalgebra.

I. INTRODUCTION

In 1966, Y. Imai and K. Iseki [5] introduced two classes of abstract algebras: BCK -algebras and BCI -algebras. It is known that the class of BCK -algebras is a proper subclass of the class of BCI -algebras. In [9] J. Neggers and H. S. Kim introduced the notion of d -algebras, which is generalization of BCK -algebras and investigated relation between d -algebras and BCK -algebras. Also they introduced the notion of B -algebras [8]. In [6] C. B. Kim, H. S. Kim introduced the notion of BG -algebras which is a generalization of B -algebras. S. S. Ahn and H. D. Lee applied the fuzzy notions to BG -algebras and introduced the notions of fuzzy BG -algebras [1]. The concept of a fuzzy set, which was introduced in [11].

In [12], Zadeh made an extension of the concept of a fuzzy set by an interval-valued fuzzy set (i.e., a fuzzy set with an interval-valued membership function). This interval-valued fuzzy set is referred to as an i-v fuzzy set, also he constructed a method of approximate inference using his i-v fuzzy sets. Biswas [2], defined interval-valued fuzzy subgroups and S. M. Hong et. al. applied the notion of interval-valued fuzzy to BCI -algebras.

In the present paper, we using the notion of interval-valued fuzzy set by Zadeh and introduced the concept of interval-valued fuzzy BG -subalgebras (briefly i-v fuzzy BG -subalgebras) of a BG -algebra, and study some of their properties. We prove that every BG -subalgebra of a BG -algebra X can be realized as an i-v level BG -subalgebra of an i-v fuzzy BG -subalgebra of X , then we obtain some related results which have been mentioned in the abstract.

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II. PRELIMINARY

Definition 2.1. [6] A BG -algebra is a non-empty set X with a constant 0 and a binary operation $*$ satisfying the following axioms:

- (I) $x * x = 0$,
 - (II) $x * 0 = x$,
 - (III) $(x * y) * (0 * y) = x$,
- for all $x, y \in X$.

For brevity we also call X a BG -algebra. In X we can define a binary relation \leq by $x \leq y$ if and only if $x * y = 0$.

Theorem 2.2. [6] In a BG -algebra X , we have the following properties:

- (i) $0 * (0 * x) = x$,
 - (ii) if $x * y = 0$, then $x = y$,
 - (iii) if $0 * x = 0 * y$, then $x = y$,
 - (iv) $(x * (0 * x)) * x = x$,
- For all $x, y \in X$.

A non-empty subset I of a BG -algebra X is called a subalgebra of X if $x * y \in I$ for any $x, y \in I$.

A mapping $f : X \rightarrow Y$ of BG -algebras is called a BG -homomorphism if $f(x * y) = f(x) * f(y)$ for all $x, y \in X$.

We now review some fuzzy logic concept (see [11]). Let X be a set. A fuzzy set A in X is characterized by a membership function $\mu_A : X \rightarrow [0, 1]$. Let f be a mapping from the set X to the set Y and let B be a fuzzy set in Y with membership function μ_B . The inverse image of B , denoted $f^{-1}(B)$, is the fuzzy set in X with membership function $\mu_{f^{-1}(B)}$ defined by $\mu_{f^{-1}(B)}(x) = \mu_B(f(x))$ for all $x \in X$.

Conversely, let A be a fuzzy set in X with membership function μ_A . Then the image of A , denoted by $f(A)$, is the fuzzy set in Y such that:

$$\mu_{f(A)}(y) = \begin{cases} \sup_{z \in f^{-1}(y)} \mu_A(z) & \text{if } f^{-1}(y) \neq \emptyset, \\ 0 & \text{otherwise} \end{cases}$$

A fuzzy set A in the BG -algebra X with the membership function μ_A is said to be have the sup property if for any subset $T \subseteq X$ there exists $x_0 \in T$ such that $\mu_A(x_0) = \sup_{t \in T} \mu_A(t)$.

An interval-valued fuzzy set (briefly, i-v fuzzy set) A defined on X is given by $A = \{(x, [\mu_A^L(x), \mu_A^U(x)])\}$, $\forall x \in X$. Briefly, denoted by $A = [\mu_A^L, \mu_A^U]$ where μ_A^L and μ_A^U are any two fuzzy sets in X such that $\mu_A^L(x) \leq \mu_A^U(x)$ for all $x \in X$.

Let $\bar{\mu}_A(x) = [\mu_A^L(x), \mu_A^U(x)]$, for all $x \in X$ and let $D[0, 1]$ denotes the family of all closed sub-intervals of $[0, 1]$. It is clear that if $\mu_A^L(x) = \mu_A^U(x) = c$, where $0 \leq c \leq 1$ then $\bar{\mu}_A(x) = [c, c]$ is in $D[0, 1]$. Thus $\bar{\mu}_A(x) \in D[0, 1]$,

for all $x \in X$. Therefore the i-v fuzzy set A is given by $A = \{(x, \bar{\mu}_A(x))\}, \forall x \in X$ where $\bar{\mu}_A : X \rightarrow D[0, 1]$.

Now we define refined minimum (briefly, rmin) and order " \leq " on elements $D_1 = [a_1, b_1]$ and $D_2 = [a_2, b_2]$ of $D[0, 1]$ as:

$$rmin(D_1, D_2) = [\min\{a_1, a_2\}, \min\{b_1, b_2\}]$$

$$D_1 \leq D_2 \iff a_1 \leq a_2 \wedge b_1 \leq b_2$$

Similarly we can define \geq and $=$.

Definition 2.3. [1] Let μ be a fuzzy set in a BG -algebra. Then μ is called a fuzzy BG -subalgebra (BG -algebra) of X if $\mu(x * y) \geq \min\{\mu(x), \mu(y)\}$ for all $x, y \in X$.

Proposition 2.4. [3] Let f be a BG -homomorphism from X into Y and G be a fuzzy BG -subalgebra of Y with the membership function μ_G . Then the inverse image $f^{-1}(G)$ of G is a fuzzy BG -subalgebra of X .

Proposition 2.5. [3] Let f be a BG -homomorphism from X onto Y and D be a fuzzy BG -subalgebra of X with the sup property. Then the image $f(D)$ of D is a fuzzy BG -subalgebra of Y .

III. INTERVAL-VALUED FUZZY BG -ALGEBRA

From now on X is a BG -algebra, unless otherwise is stated.

Definition 3.1. An i-v fuzzy set A in X is called an interval-valued fuzzy BG -subalgebras (briefly i-v fuzzy BG -subalgebra) of X if:

$$\bar{\mu}_A(x * y) \geq rmin\{\bar{\mu}_A(x), \bar{\mu}_A(y)\}$$

for all $x, y \in X$.

Example 3.2. Let $X = \{0, 1, 2, 3\}$ be a set with the following table:

*	0	1	2	3
0	0	1	2	3
1	1	0	3	2
2	2	3	0	1
3	3	2	1	0

Then X is a BG -algebra. Define $\bar{\mu}_A$ as:

$$\bar{\mu}_A(x) = \begin{cases} [0.3, 0.9] & \text{if } x \in \{0, 2\} \\ [0.1, 0.6] & \text{Otherwise} \end{cases}$$

It is easy to check that A is an i-v fuzzy BG -subalgebra of X .

Lemma 3.3. If A is an i-v fuzzy BG -subalgebra of X , then for all $x \in X$

$$\bar{\mu}_A(0) \geq \bar{\mu}_A(x).$$

Proof. For all $x \in X$, we have

$$\begin{aligned} \bar{\mu}_A(0) &= \bar{\mu}_A(x * x) \geq rmin\{\bar{\mu}_A(x), \bar{\mu}_A(x)\} \\ &= rmin\{\mu_A^L(x), \mu_A^U(x)\}, [\mu_A^L(x), \mu_A^U(x)] \\ &= [\mu_A^L(x), \mu_A^U(x)] = \bar{\mu}_A(x). \end{aligned}$$

Theorem 3.4. Let A be an i-v fuzzy BG -subalgebra of X . If there exists a sequence $\{x_n\}$ in X , such that $\lim_{n \rightarrow \infty} \bar{\mu}_A(x_n) = [1, 1]$ Then $\bar{\mu}_A(0) = [1, 1]$.

Proof. By Lemma 3.3, we have $\bar{\mu}_A(0) \geq \bar{\mu}_A(x)$, for all $x \in X$, thus $\bar{\mu}_A(0) \geq \bar{\mu}_A(x_n)$, for every positive integer n . Consider

$$[1, 1] \geq \bar{\mu}_A(0) \geq \lim_{n \rightarrow \infty} \bar{\mu}_A(x_n) = [1, 1].$$

Hence $\bar{\mu}_A(0) = [1, 1]$.

Theorem 3.5. An i-v fuzzy set $A = [\mu_A^L, \mu_A^U]$ in X is an i-v fuzzy BG -subalgebra of X if and only if μ_A^L and μ_A^U are fuzzy BG -subalgebra of X .

Proof. Let μ_A^L and μ_A^U are fuzzy BG -subalgebra of X and $x, y \in X$, consider

$$\begin{aligned} \bar{\mu}_A(x * y) &= [\bar{\mu}_A(x * y), \bar{\mu}_A(x * y)] \\ &\geq [\min\{\mu_A^L(x), \mu_A^L(y)\}, \min\{\mu_A^U(x), \mu_A^U(y)\}] \\ &= rmin\{[\mu_A^L(x), \mu_A^U(x)], [\mu_A^L(y), \mu_A^U(y)]\} \\ &= rmin\{\bar{\mu}_A(x), \bar{\mu}_A(y)\}. \end{aligned}$$

This completes the proof.

Conversely, suppose that A is an i-v fuzzy BG -subalgebras of X . For any $x, y \in X$ we have

$$\begin{aligned} [\mu_A^L(x * y), \mu_A^U(x * y)] &= \bar{\mu}_A(x * y) \\ &\geq rmin\{\bar{\mu}_A(x), \bar{\mu}_A(y)\} \\ &= rmin\{[\mu_A^L(x), \mu_A^U(x)], [\mu_A^L(y), \mu_A^U(y)]\} \\ &= [\min\{\mu_A^L(x), \mu_A^L(y)\}, \min\{\mu_A^U(x), \mu_A^U(y)\}]. \end{aligned}$$

Therefore $\mu_A^L(x * y) \geq \min\{\mu_A^L(x), \mu_A^L(y)\}$ and $\mu_A^U(x * y) \geq \min\{\mu_A^U(x), \mu_A^U(y)\}$, hence we get that μ_A^L and μ_A^U are fuzzy BG -subalgebras of X .

Theorem 3.6. Let A_1 and A_2 are i-v fuzzy BG -subalgebras of X . Then $A_1 \cap A_2$ is an i-v fuzzy BG -subalgebras of X .

Corollary 3.7. Let $\{A_i | i \in \Lambda\}$ be a family of i-v fuzzy BG -subalgebras of X . Then $\bigcap_{i \in \Lambda} A_i$ is also an i-v fuzzy BG -subalgebras of X .

Definition 3.8. Let A be an i-v fuzzy set in X and $[\delta_1, \delta_2] \in D[0, 1]$. Then the i-v level BG -subalgebra $U(A; [\delta_1, \delta_2])$ of A and strong i-v BG -subalgebra $U(A; >, [\delta_1, \delta_2])$ of X are defined as following:

$$U(A; [\delta_1, \delta_2]) := \{x \in X | \bar{\mu}_A(x) \geq [\delta_1, \delta_2]\},$$

$$U(A; >, [\delta_1, \delta_2]) := \{x \in X \mid \bar{\mu}_A(x) > [\delta_1, \delta_2]\}.$$

Theorem 3.9. Let A be an i-v fuzzy BG -subalgebra of X and B be closure of image of μ_A . Then the following condition are equivalent :

- (i) A is an i-v fuzzy BG -subalgebra of X .
- (ii) For all $[\delta_1, \delta_2] \in Im(\mu_A)$, the nonempty level subset $U(A; [\delta_1, \delta_2])$ of A is a BG -subalgebra of X .
- (iii) For all $[\delta_1, \delta_2] \in Im(\mu_A) \setminus B$, the nonempty strong level subset $U(A; >, [\delta_1, \delta_2])$ of A is a BG -subalgebra of X .
- (iv) For all $[\delta_1, \delta_2] \in D[0, 1]$, the nonempty strong level subset $U(A; >, [\delta_1, \delta_2])$ of A is a BG -subalgebra of X .
- (v) For all $[\delta_1, \delta_2] \in D[0, 1]$, the nonempty level subset $U(A; [\delta_1, \delta_2])$ of A is a BG -subalgebra of X .

Proof. (i \rightarrow iv) Let A be an i-v fuzzy BG -subalgebra of X , $[\delta_1, \delta_2] \in D[0, 1]$ and $x, y \in U(A; <, [\delta_1, \delta_2])$, then we have $\bar{\mu}_A(x * y) \geq rmin\{\bar{\mu}_A(x), \bar{\mu}_A(y)\} > rmin\{[\delta_1, \delta_2], [\delta_1, \delta_2]\} = [\delta_1, \delta_2]$ thus $x * y \in U(A; >, [\delta_1, \delta_2])$. Hence $U(A; >, [\delta_1, \delta_2])$ is a BG -subalgebra of X .

(iv \rightarrow iii) It is clear.
 (iii \rightarrow ii) Let $[\delta_1, \delta_2] \in Im(\mu_A)$. Then $U(A; [\delta_1, \delta_2])$ is a nonempty. Since $U(A; [\delta_1, \delta_2]) = \bigcap_{[\delta_1, \delta_2] > [\alpha_1, \alpha_2]} U(A; >, [\delta_1, \delta_2])$, where $[\alpha_1, \alpha_2] \in Im(\mu_A) \setminus B$. Then by (iii) and Corollary 3.8, $U(A; [\delta_1, \delta_2])$ is a BG -subalgebra of X .

(ii \rightarrow v) Let $[\delta_1, \delta_2] \in D[0, 1]$ and $U(A; [\delta_1, \delta_2])$ be nonempty. Suppose $x, y \in U(A; [\delta_1, \delta_2])$. Let $[\beta_1, \beta_2] = min\{\mu_A(x), \mu_A(y)\}$, it is clear that $[\beta_1, \beta_2] = min\{\mu_A(x), \mu_A(y)\} \geq \{[\delta_1, \delta_2], [\delta_1, \delta_2]\} = [\delta_1, \delta_2]$. Thus $x, y \in U(A; [\beta_1, \beta_2])$ and $[\beta_1, \beta_2] \in Im(\mu_A)$, by (ii) $U(A; [\beta_1, \beta_2])$ is a BG -subalgebra of X , hence $x * y \in U(A; [\beta_1, \beta_2])$. Then we have $\bar{\mu}_A(x * y) \geq rmin\{\mu_A(x), \mu_A(y)\} \geq \{[\beta_1, \beta_2], [\beta_1, \beta_2]\} = [\beta_1, \beta_2] \geq [\delta_1, \delta_2]$. Therefore $x * y \in U(A; [\delta_1, \delta_2])$. Then $U(A; [\delta_1, \delta_2])$ is a BG -subalgebra of X .

(v \rightarrow i) Assume that the nonempty set $U(A; [\delta_1, \delta_2])$ is a BG -subalgebra of X , for every $[\delta_1, \delta_2] \in D[0, 1]$. In contrary, let $x_0, y_0 \in X$ be such that

$$\bar{\mu}_A(x_0 * y_0) < rmin\{\bar{\mu}_A(x_0), \bar{\mu}_A(y_0)\}.$$

Let $\bar{\mu}_A(x_0) = [\gamma_1, \gamma_2]$, $\bar{\mu}_A(y_0) = [\gamma_3, \gamma_4]$ and $\bar{\mu}_A(x_0 * y_0) = [\delta_1, \delta_2]$. Then

$$[\delta_1, \delta_2] < rmin\{[\gamma_1, \gamma_2], [\gamma_3, \gamma_4]\} = [min\{\gamma_1, \gamma_3\}, min\{\gamma_2, \gamma_4\}].$$

So $\delta_1 < min\{\gamma_1, \gamma_3\}$ and $\delta_2 < min\{\gamma_2, \gamma_4\}$.

Consider

$$[\lambda_1, \lambda_2] = \frac{1}{2}\bar{\mu}_A(x_0 * y_0) + rmin\{\bar{\mu}_A(x_0), \bar{\mu}_A(y_0)\}$$

We get that

$$\begin{aligned} [\lambda_1, \lambda_2] &= \frac{1}{2}([\delta_1, \delta_2] + min\{\gamma_1, \gamma_3\}, min\{\gamma_2, \gamma_4\}) \\ &= [\frac{1}{2}(\delta_1 + min\{\gamma_1, \gamma_3\}), \frac{1}{2}(\delta_2 + min\{\gamma_2, \gamma_4\})] \end{aligned}$$

Therefore

$$min\{\gamma_1, \gamma_3\} > \lambda_1 = \frac{1}{2}(\delta_1 + min\{\gamma_1, \gamma_3\}) > \delta_1$$

$$min\{\gamma_2, \gamma_4\} > \lambda_2 = \frac{1}{2}(\delta_2 + min\{\gamma_2, \gamma_4\}) > \delta_2$$

Hence

$$[min\{\gamma_1, \gamma_3\}, min\{\gamma_2, \gamma_4\}] > [\lambda_1, \lambda_2] > [\delta_1, \delta_2] = \bar{\mu}_A(x_0 * y_0)$$

so that $x_0 * y_0 \notin U(A; [\delta_1, \delta_2])$

which is a contradiction, since

$$\bar{\mu}_A(x_0) = [\gamma_1, \gamma_2] \geq [min\{\gamma_1, \gamma_3\}, min\{\gamma_2, \gamma_4\}] > [\lambda_1, \lambda_2]$$

$$\bar{\mu}_A(y_0) = [\gamma_3, \gamma_4] \geq [min\{\gamma_1, \gamma_3\}, min\{\gamma_2, \gamma_4\}] > [\lambda_1, \lambda_2]$$

imply that $x_0, y_0 \in U(A; [\delta_1, \delta_2])$. Thus $\bar{\mu}_A(x * y) \geq rmin\{\bar{\mu}_A(x), \bar{\mu}_A(y)\}$ for all $x, y \in X$. Which completes the proof.

Theorem 3.10. Each BG -subalgebra of X is an i-v level BG -subalgebra of an i-v fuzzy BG -subalgebra of X .

Proof. Let Y be a BG -subalgebra of X , and A be an i-v fuzzy set on X defined by

$$\bar{\mu}_A(x) = \begin{cases} [\alpha_1, \alpha_2] & \text{if } x \in Y \\ [0, 0] & \text{Otherwise} \end{cases}$$

where $\alpha_1, \alpha_2 \in [0, 1]$ with $\alpha_1 < \alpha_2$. It is clear that $U(A; [\alpha_1, \alpha_2]) = Y$. Let $x, y \in X$. We consider the following cases:

case 1) If $x, y \in Y$, then $x * y \in Y$ therefore $\bar{\mu}_A(x * y) = [\alpha_1, \alpha_2] = rmin\{[\alpha_1, \alpha_2], [\alpha_1, \alpha_2]\} = rmin\{\bar{\mu}_A(x), \bar{\mu}_A(y)\}$.

case 2) If $x, y \notin Y$, then $\bar{\mu}_A(x) = [0, 0] = \bar{\mu}_A(y)$ and so $\bar{\mu}_A(x * y) \geq [0, 0] = rmin\{[0, 0], [0, 0]\} = rmin\{\bar{\mu}_A(x), \bar{\mu}_A(y)\}$.

case 3) If $x \in Y$ and $y \notin Y$, then $\bar{\mu}_A(x) = [\alpha_1, \alpha_2]$ and $\bar{\mu}_A(y) = [0, 0]$. Thus $\bar{\mu}_A(x * y) \geq [0, 0] = rmin\{[\alpha_1, \alpha_2], [0, 0]\} = rmin\{\bar{\mu}_A(x), \bar{\mu}_A(y)\}$.

case 4) If $y \in Y$ and $x \notin Y$, then by the same argument as in case 3, we can conclude that $\bar{\mu}_A(x * y) \geq rmin\{\bar{\mu}_A(x), \bar{\mu}_A(y)\}$.

Therefore A is an i-v fuzzy BG -subalgebra of X .

Theorem 3.11. If A is an i-v fuzzy BG -subalgebra of X , then the set

$$X_{\bar{\mu}_A} := \{x \in X \mid \bar{\mu}_A(x) = \bar{\mu}_A(0)\}$$

is a BG -subalgebra of X .

Definition 3.12. [2] Let f be a mapping from the set X into a set Y . Let B be an i-v fuzzy set in Y . Then the inverse image of B , denoted by $f^{-1}[B]$, is the i-v fuzzy set in X with the

membership function given by $\bar{\mu}_{f^{-1}[B]}(x) = \bar{\mu}_B(f(x))$, for all $x \in X$.

Lemma 3.13. [2] Let f be a mapping from the set X into a set Y . Let $m = [m^L, m^U]$ and $n = [n^L, n^U]$ be i-v fuzzy sets in X and Y respectively. Then

- (i) $f^{-1}(n) = [f^{-1}(n^L), f^{-1}(n^U)]$,
- (ii) $f(m) = [f(m^L), f(m^U)]$,

Proposition 3.14. Let f be a BG -homomorphism from X into Y and G be an i-v fuzzy BG -subalgebra of Y with the membership function μ_G . Then the inverse image $f^{-1}[G]$ of G is an i-v fuzzy BG -subalgebra of X .

Proof. Since $B = [\mu_B^L, \mu_B^U]$ is an i-v fuzzy BG -subalgebra of Y , by Theorem 3.5, we get that μ_B^L and μ_B^U are fuzzy BG -subalgebra of Y . By Proposition 2.4, $f^{-1}[\mu_B^L]$ and $f^{-1}[\mu_B^U]$ are fuzzy BG -subalgebra of X , by above lemma and Theorem 3.5, we can conclude that $f^{-1}(B) = [f^{-1}(\mu_B^L), f^{-1}(\mu_B^U)]$ is an i-v fuzzy BG -subalgebra of X .

Definition 3.15. [2] Let f be a mapping from the set X into a set Y , and A be an i-v fuzzy set in X with membership function μ_A . Then the image of A , denoted by $f[A]$, is the i-v fuzzy set in Y with membership function defined by:

$$\bar{\mu}_{f[A]}(y) = \begin{cases} \text{rsup}_{z \in f^{-1}(y)} \bar{\mu}_A(z) & \text{if } f^{-1}(y) \neq \emptyset \\ [0,0] & \text{otherwise} \end{cases}$$

Where $f^{-1}(y) = \{x \mid f(x) = y\}$.

Theorem 3.16. Let f be a BG -homomorphism from X onto Y . If A is an i-v fuzzy BG -subalgebra of X , then the image $f[A]$ of A is an i-v fuzzy BG -subalgebra of Y .

Proof. Assume that A is an i-v fuzzy BG -subalgebra of X , then $A = [\mu_A^L, \mu_A^U]$ is an i-v fuzzy BG -subalgebra of X and only if μ_A^L and μ_A^U are fuzzy BG -subalgebra of X . By Proposition 2.5, $f[\mu_A^L]$ and $f[\mu_A^U]$ are fuzzy BG -subalgebra of Y , by Lemma 3.13, and Theorem 3.5, we can conclude that $f[A] = [f[\mu_A^L], f[\mu_A^U]]$ is an i-v fuzzy BG -subalgebra of Y .

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