**Fuzzy soft $\Gamma$-hyperrings**

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**Abstract**

Maji et al. introduced the concept of fuzzy soft sets as a generalization of the standard soft sets and presented an application of fuzzy soft sets in a decision making problem. In this paper, we apply fuzzy soft sets to $\Gamma$-hyperrings. The concept of $(\epsilon, \eta, q_a, \epsilon, q_a)\text{-fuzzy soft }\Gamma\text{-hyperideal}$ of $\Gamma$-hyperrings is first introduced. Some new characterizations are investigated. In particular, a kind of new $\Gamma$-hyperrings by congruence relations is obtained.

**Keywords:** Soft set; $\Gamma\text{-hyperideal}$; $(\epsilon, \eta, q_a, \epsilon, q_a)\text{-fuzzy soft }\Gamma\text{-hyperideal}$; congruence relation; $\Gamma\text{-hyperring}$

**1. Introduction**

Uncertainties, which could be caused by information incompleteness, data randomness limitations of measuring instruments, etc., are pervasive in many complicated problems in biology, engineering, economics, environment, medical science and social science. Alternatively, mathematical theories, such as probability theory, fuzzy set theory [1], vague set theory, rough set theory [2] and interval mathematics, have been proven to be useful mathematical tools for dealing with uncertainties. However, all these theories have their inherent difficulties, as pointed out by Molodtsov in [3]. Nowadays, works on the soft set theory are progressing rapidly. Maji et al. [4, 5] described the application of soft set theory to a decision making problem. Ali et al. [6] proposed some new operations on soft sets. Chen et al. [7] presented a new definition of soft set parametrization reduction, and compared this definition to the related concept of attribute reduction in rough set theory. In particular, fuzzy soft set theory has been investigated by some researchers, for examples, see [8, 9]. Recently, the algebraic structures of soft sets have been studied increasingly, see [10-18].

On the other hand, the theory of algebraic hyperstructures (or hypersystems) is a well established branch of classical algebraic theory. In the literature, the theory of hyperstructure was first initiated by Marty in 1934 [19] when he defined the hypergroups and began to investigate their properties with applications to groups, rational fractions and algebraic functions. Later on, many people observed that the theory of hyperstructures also has many applications in both pure and applied sciences, for example, semi-hypergroups are the simplest algebraic hyperstructures which possess the properties of closure and associativity. Some review of the theory of hyperstructures can be found in [20-23], respectively. One well-known type of a hyperring, is called the Krasner hyper-ring [24]. Krasner hyperrings are essentially rings with approximately modified axioms in which addition is a hyperoperation (i.e., $a + b$ is a set). This concept has been studied by a variety of authors, see [25-28]. In particular, the relationships between the fuzzy sets and algebraic hyperstructures have been considered by Ameri, Cristea, Corsini, Davvaz, Leoreanu, Zhan and many other researchers [18, 29-42].

A different way of [49], Yin et al. [50] considered the concept of $\Gamma\text{-rings}$ was introduced by Barnes [43]. After that, this concept was discussed further by some researchers. The notion of fuzzy ideals in a $\Gamma\text{-ring}$ was introduced by Jun and Lee in [44]. They studied some preliminary properties of fuzzy ideals of $\Gamma\text{-rings}$. Jun [45] defined fuzzy prime ideals of a $\Gamma\text{-ring}$ and obtained a number of characterizations for a fuzzy ideal to be a fuzzy prime ideal. In particular, Dutta and Chanda [46] studied the structures of the set of fuzzy ideals of a $\Gamma\text{-ring}$. Ma et al. [47, 48] considered the characterizations of $\Gamma\text{-hemirings}$ and $\Gamma\text{-rings}$, respectively. Recently, Ameri et al. [4] considered the concept of fuzzy hyperideals of $\Gamma\text{-hyperrings}$. By a different way of [49], Yin et al. [50]
investigated some new results on $\Gamma$-hyperrings. Ma et al. [51] considered the (fuzzy) isomorphism theorems of $\Gamma$-hyperrings. At the same time, Davvaz et al. [52] considered the properties of $\Gamma$-hypernear-rings and derived some related results.

After the introduction of fuzzy sets by Zadeh [1], there have been a number of generalizations of this fundamental concept. A new type of fuzzy subgroup, that is, the $(e, e \in \nu_q)$-fuzzy subgroup, was introduced in an earlier paper of Bhakat and Das [53] by using the combined notions of “belongingness” and “quasicoincidence” of fuzzy points and fuzzy sets. In fact, the $(e, e \in \nu_q)$-fuzzysubgroup is an important generalization of Rosenfeld’s fuzzy subgroup. It is now natural to investigate similar types of generalizations of the existing fuzzy subsystems with other algebraic structures, see [28, 31, 33, 37, 39].

In this paper, we introduce the concept of $(e, e \in \nu_q)$-fuzzy soft $\Gamma$-hyperideals of $\Gamma$-hyperrings. Some new characterization of them are investigated. In particular, a new kind of $\Gamma$-hyperrings are obtained by congruence relations.

2. Preliminaries

A hyperringoid is a non-empty set $H$ together with a mapping “$+$” : $H \times H \rightarrow P(H)$, where $P(H)$ is the set of all the non-empty subsets of $H$.

A quasicylindrical hypergroup (not necessarily commutative) is an algebraic structure $(H, +, \cdot)$ satisfying the following conditions:

(i) For every $x, y, z \in H$, $x + (y + z) = (x + y) + z$;

(ii) There exists a $0 \in H$ such that $0 + x = x$, for all $x \in H$;

(iii) For every $x \in H$, there exists a unique element $x \in H$ such that $0 \in (x + x) \cap (x + x)$: “we call the element $-x$ the opposite of $x$”

(iv) $z \in x + y$ implies $y \in -x + z$ and $x \in z - y$.

Quasicylindrical hypergroups are also called polygroups.

We note that if $x \in H$ and $A; B$ are non-empty subsets in $H$, then by $A + B$, $A + x$ and $x + B$ we mean that $A + B = \bigcup_{a \in A, b \in B} a + b$, $A + x = A + \{x\}$ and $x + B = \{x\} + B$, respectively. Also, for all $x, y \in H$, we have $-(x + y) = x + y$ and $y$ is unique and $-(x + y) = -y - x$.

A sub-hypergroup $A \subset H$ is said to be normal if $x + A - x \subseteq H$ for all $x \in H$.

A normal sub-hypergroup $A$ of $H$ is called left (right) hyperideal of $H$ if $xA \subseteq A$ ($Ax \subseteq A$ respectively) for all $x \in H$. Moreover, $A$ is said to be a hyperideal of $H$ if it is both a left and a right hyperideal of $H$. A canonical hypergroup is a commutative quasicylindrical hypergroup.

Definition 2.1. [24] A hyperring is an algebraic structure $(R, +, \cdot)$ which satisfies the following axioms:

1. $(R, +)$ is a canonical hypergroup;

2. Relating to the multiplication, $(R, \cdot)$ is a semigroup having zero as a bilaterally absorbing element, that is, $0 \cdot x = x \cdot 0 = 0$ for all $x \in R$;

3. The multiplication is distributive with respect to the hyperoperation “$+$” that is, $z \cdot (x + y) = z \cdot x + z \cdot y$ and $(x + y) \cdot z = x \cdot z + y \cdot z$ for all $x, y, z \in R$.

For the sake of simplicity, we shall omit the symbol “$:$”, writing $a \cdot b$ for $a - b (a, b \in R)$.

Definition 2.2. [49, 50] Let $(R, \circ, \oplus)$ and $(\Gamma, \oplus)$ be two canonical hypergroups. Then $R$ is called a $\Gamma$-hyperring, if the following conditions are satisfied for all $x, y, z \in R$ and for all $\alpha, \beta \in \Gamma$,

1. $x \alpha y \in R$;

2. $(x \circ y) \alpha z = xz \circ yz$

3. $x(\alpha \oplus \beta) y = (y \alpha )z \oplus (x \beta )y$;

4. $x \alpha y \circ z = (x \alpha y) \beta z$.

In the sequel, unless otherwise stated, $(R, \circ, \oplus, \Gamma)$ always denotes a $\Gamma$-hyperring.

A subset $A$ in $R$ is said to be a left (right) $\Gamma$-hyperideal of $R$ if it satisfies the following conditions:

1. $(A, \circ, \oplus)$ is a normal sub-hypergroup of $(R, \circ, \oplus)$;

2. $x \alpha y \in A$ (for all $x \in R$ respectively) for all $x \in R$, $y \in A$ and $\alpha \in \Gamma$.

$A$ is said to be a $\Gamma$-hyperideal of $R$ if it is both a left and a right $\Gamma$-hyperideal of $R$.

Definition 2.3. [51] A fuzzy set $\mu$ of a $\Gamma$-hyperring $R$ is called a fuzzy $\Gamma$-hyperideal of $R$ if the following conditions hold:

1. $\min \{\mu(x), \mu(y)\} \leq \inf_{z \in x+y} \mu(z)$ for all $x, y \in R$;

2. $\mu(x) \leq \mu(-x)$ for all $x \in R$;

3. $\max_{\alpha \in \Gamma} \{\mu(x), \mu(y)\} \leq \mu(x + y)$ for all $x, y \in R$ and for all $\alpha \in \Gamma$;

4. $\mu(x) \leq \inf_{z \in y \circ x+y} \mu(z)$ for all $x, y \in R$.

Example 1. [51] Let $R$ be a $\Gamma$-ring such that $x(-\alpha) y = -\alpha xy$ for all $x, y \in R$ and $\alpha \in \Gamma$. 
Denote $\mathcal{R} = \{x = [x, -x] | x \in R\}$ and $\Gamma = \{\|a, -a\| | a \in \Gamma\}$.

Define the hyperoperations on $R$ and $\Gamma$ as follows: $\mathcal{R} \oplus \mathcal{R} = \{x + y, x - y\}$, $\mathcal{R} \oplus \mathcal{R} = \{a + \beta, a - \beta\}$ and $x \alpha \gamma y = x \alpha y$ for all $x, y \in R$ and $\alpha, \gamma \in \Gamma$. Then $(R, \oplus, \Gamma)$ is a $\Gamma$-hyperring.

**Example 2.** [51] Let $(G, \cdot)$ be a group and $\Gamma = G \setminus \{e\}$. Denote $G^\# = G \cup \{0\}$ and define $x \cdot y = x \cdot y$ for all $x, y \in G$ and $\alpha \in \Gamma$. Then $(G^\#, \oplus, \Gamma^\#)$ is a $\Gamma^\#$-hyperring with respect to the hyperoperation “@” on $G^\#$ and $\Gamma^\#$, defined by $x @ 0 = 0 @ x = \{x\}$ for all $x \in G^\#$, $x @ x = G^\# \setminus \{0\}$ for all $x \in G^\# \setminus \{0\}$, $x @ y = \{x, y\}$ for all $x, y \in G^\# \setminus \{0\}$ with $x \neq y$, and $\alpha @ 0 = 0 @ \alpha = \{\alpha\}$ for all $\alpha \in \Gamma^\#$, $\alpha @ \alpha = \{\alpha\} \setminus \{0\}$ for all $\alpha \neq \{\alpha\}$, $\alpha @ \beta = \{\alpha, \beta\}$ for all $\alpha, \beta \in \Gamma^\# \setminus \{0\}$ with $\alpha \neq \beta$, respectively.

**Definition 2.4.** [51] If $R$ and $R'$ are $\Gamma$-hyperrings, then a mapping $f : R \rightarrow R'$ such that $f(x \oplus y) = f(x) \oplus f(y)$ and $f(x \gamma y) = f(x) \alpha f(y)$ for all $x, y \in R$ and $\alpha \in \Gamma$, is called a $\Gamma$-hyperring homomorphism. Clearly, a $\Gamma$-hyperring homomorphism $f$ is an isomorphism if $f$ is injective and surjective. We write $R \cong R'$ if $R$ is isomorphic to $R'$.

If $N$ is a $\Gamma$-hyperideal of $R$, then we define the relation $N'$ by $x$ congruent $y \Leftrightarrow (x - y) \cap N \neq \emptyset$. This is a congruence relation on $R$.

Let $N$ be a $\Gamma$-hyperideal of $R$. Then, for $x, y \in N$, the following are equivalent:

1. $(x - y) \cap N \neq \emptyset$,
2. $x - y \subseteq N$,
3. $y \in x + N$.

The class $x + N$ is represented by $x$ and we denote it with $N' (x)$. Moreover,

$$N'(x) = N'(y) \text{ if and only if } x = y \text{ (mod } N).$$

We can define $R / N$ as follows:

$$R / N = \{N'(x) | x \in R\}.$$

Define a hyperoperation $\oplus$ and an operation $\ominus$ on $R / N$ by

$$N'(x) \oplus N'(y) = \{N'(z) | z \in N'(x) \oplus N'(y)\} \text{; } N'(x) \ominus N'(y) = N'(x \alpha y)$$

for all $N'(x), N'(y) \in R / N$.

Then, $(R / N, \oplus, \ominus)$ is a $\Gamma$-hyperring, see [51].

### 3. Fuzzy soft sets

A fuzzy set $\mu$ of $R$ of the form

$$\mu(x) = \begin{cases} t(x) & \text{if } y = x, \\ 0 & \text{if } y \neq x, \end{cases}$$

is said to be a fuzzy point with support $x$ and value $t$ and is denoted by $x$. A fuzzy point $x$, is said to be “belong to” (resp., “quasi – coincident with”) a fuzzy set $\mu$, written as $x \in \mu$ (resp., $x \in q\mu$) if $\mu(x) \geq t$ (resp., $\mu(x) + t > 1$). If $x \in \mu$ or $x \in q\mu$, then we write $x \in v\mu$. If $\mu(x) < t$ (resp., $\mu(x) + t > 1$), then we say that $x \in u\mu$ (resp., $x \in q\mu$).

We note here that the symbol $\in v\mu$ means that $\in v\mu$ does not hold.

Let $x, \gamma \in [0, 1]$ be such that $x \leq \gamma$. For a fuzzy point $x$, $\mu$ of $X$, we say

1. $x \in e_x \mu$ if $\mu(x) \geq r > \gamma$.
2. $x \in q\mu$ if $\mu(x) + t > 2 \delta$.
3. $x \in e_x \end{cases}$
4. $x \in q\mu$ if $x \in q\mu$ or $x \in q\mu$.

Molodtsov [41] defined the soft set in the following way: let $U$ be an initial universe set, $E$ a set of parameters and $A \subseteq E$.

A pair $(F, A)$ is called a soft set over $U$, if $F$ is a mapping given by $F : A \rightarrow P(U)$.

In other words, a soft set over $U$ is a parameterized family of subsets of the universe $U$. For $e \in A, F(e)$ may be considered as the set of $e$-approximate elements of the soft set $(F, A)$.

**Definition 3.1.** [8] Let $U$ be an initial universe set, $E$ a set of parameters and $A \subseteq E$. Then $(F, A)$ is called a fuzzy soft set over $U$, where $F$ is a mapping given by $F : A \rightarrow P(U)$.

In general, for every $x \in A, F(x)$ is a fuzzy set in $U$ and it is called fuzzy value set of parameter.
x. If for every $x \in A$, $\overline{F}(x)$ is a crisp subset of $U$.

Then $(\overline{F}, A)$ is degenerated to be the standard soft set. Thus, from the above definition, it is clear that fuzzy soft sets are a generalization of standard soft sets.

Let $A \subseteq E$ and $F \in F(U)$. Let $(\overline{F}, A)$ be a fuzzy soft set by $\overline{F}(\alpha) = F$ for all $\alpha \in A$. For any fuzzy point $x_\alpha$ in $U$, define $(x_\alpha, A)$ as a fuzzy soft set by $x_\alpha[\alpha] = x_\alpha$ for all $\alpha \in A$.

The notions of AND, OR and bi-intersection operations of fuzzy soft sets can be found in [3, 4].

Now, we introduce a new ordered relation; “$\subseteq \forall q_{(r, \delta)}$” on the set of all fuzzy soft sets over $U$.

For two fuzzy soft sets $(\overline{F}, A)$ and $(\overline{G}, B)$ over $U$, by $(\overline{F}, A) \subseteq \forall q_{(r, \delta)} (\overline{G}, B)$ we mean that $A \subseteq B$ and $x, e_\alpha \in \overline{F}[\alpha] \Rightarrow x, e_\alpha \in \forall q_{(r, \delta)} \overline{G}[\alpha]$ for all $\alpha \in A, x \in U$ and $r \in (\gamma, 1]$.

**Definition 3.2.** For two fuzzy soft sets $(\overline{F}, A)$ and $(\overline{G}, B)$ over $U$, we say that $(\overline{F}, A)$ is an $(e_\gamma, e_\gamma, \forall q_{(r, \delta)})$-fuzzy soft subset of $(\overline{G}, B)$, if $(\overline{F}, A) \subseteq \forall q_{(r, \delta)} (\overline{G}, B)$.

$(\overline{F}, A)$ and $(\overline{G}, B)$ are said to be $(e_\gamma, e_\gamma, \forall q_{(r, \delta)})$-equal if $(\overline{F}, A) \subseteq \forall q_{(r, \delta)} (\overline{G}, B)$ and $(\overline{G}, B) \subseteq \forall q_{(r, \delta)} (\overline{F}, A)$. This is denoted by $(\overline{F}, A) = (\overline{G}, B)$.

The following two lemmas are obvious.

**Lemma 3.3.** Let $(\overline{F}, A)$ and $(\overline{G}, B)$ be two fuzzy soft sets over $U$. Then $(\overline{F}, A) \subseteq \forall q_{(r, \delta)} (\overline{G}, B)$ if and only if $\max \overline{G}[\alpha](x, y) \geq \min \overline{F}[\alpha](x, \delta)$ for all $\alpha \in A, x \in U$.

**Lemma 3.4.** Let $(\overline{F}, A)$ $(\overline{G}, B)$ and $(\overline{H}, C)$ be fuzzy soft sets over $U$ such that $(\overline{F}, A) \subseteq \forall q_{(r, \delta)} (\overline{G}, B)$ and $(\overline{G}, B) \subseteq \forall q_{(r, \delta)} (\overline{H}, C)$. Then $(\overline{F}, A) \subseteq \forall q_{(r, \delta)} (\overline{H}, C)$.

It follows from Lemmas 3.1 and 3.2 that “$= (r, \delta)$” is an equivalence relation on the set of all fuzzy soft sets over $U$.

Now, let us define some operations of fuzzy subsets of $R$.

**Definition 3.5.** Let $\mu, \nu \in F(R)$ and $\alpha \in \Gamma$. We define fuzzy subsets $-\mu$, $\mu \oplus \nu$ and $\mu @ \nu$ by

$$
-\mu(x) = \mu(-x),
$$
$$
(\mu \oplus \nu)(x) = \sup_{x \in R} \min \{\mu(y), \mu(z)\}
$$
and

$$
(\mu @ \nu)(x) = \begin{cases} 
\sup \{\mu(y), \mu(z)\}, & \text{if } \exists y, z \in R, x = yz \\
0, & \text{otherwise}
\end{cases}
$$

respectively, for all $x \in R$ and $\alpha \in \Gamma$.

**Definition 3.6.** Let $(\overline{F}, A)$ and $(\overline{G}, B)$ be two fuzzy soft sets over $R$. The sum of $(\overline{F}, A)$ and $(\overline{G}, B)$, denoted by $(\overline{F}, A) \oplus (\overline{G}, B)$, is defined to be the fuzzy soft set $(\overline{F}, A) \oplus (\overline{G}, B) = (\overline{F} \oplus \overline{G}, C)$ over $R$, where $C = A \cup B$ and

$$(\overline{F} \oplus \overline{G})(\alpha)(x) = \begin{cases} 
\overline{F}[\alpha](x), & \text{if } \alpha \in A - B, \\
\overline{G}[\alpha](x), & \text{if } \alpha \in B - A, \\
(\overline{F}[\alpha] \oplus \overline{G}[\alpha])(x), & \text{if } \alpha \in A \cap B,
\end{cases}
$$

for all $\alpha \in C \subseteq C$ and $x \in R$.

**Definition 3.7.** Let $(\overline{F}, A)$ and $(\overline{G}, B)$ be two fuzzy soft sets over $R$. The $\alpha$-product of $(\overline{F}, A)$ and $(\overline{G}, B)$, denoted by $(\overline{F}, A) @ (\overline{G}, B)$, is defined to be the fuzzy soft set $(\overline{F}, A) @ (\overline{G}, B) = (\overline{F} @ \overline{G}, C)$ over $R$, where $C = A \cup B$ and

$$(\overline{F} @ \overline{G})(\alpha)(x) = \begin{cases} 
\overline{F}[\alpha](x), & \text{if } \alpha \in A - B, \\
\overline{G}[\alpha](x), & \text{if } \alpha \in B - A, \\
(\overline{F}[\alpha] \oplus \overline{G}[\alpha])(x), & \text{if } \alpha \in A \cap B,
\end{cases}
$$

for all $\alpha \in C \subseteq C$ and $x \in R$.

4. $(e_\gamma, e_\gamma, \forall q_{(r, \delta)})$-fuzzy soft $\Gamma$-hyperideals

In this section, we concentrate our study on the $(e_\gamma, e_\gamma, \forall q_{(r, \delta)})$-fuzzy soft $\Gamma$-hyperideals of $\Gamma$-hyperrings.

**Definition 4.1.** A fuzzy soft set $(\overline{F}, A)$ over $R$ is called an $(e_\gamma, e_\gamma, \forall q_{(r, \delta)})$-fuzzysoft left (resp., right) $\Gamma$-hyperideal of $R$ if for all $\alpha \in A, r, s \in (\gamma, 1]$ and $x, y \in R$:
(F1a) \( x, y \in F[\alpha] \) and \( y, z \in F[\alpha] \) imply 
\[ z_{\min_{\gamma}} = \max \{ \min \{ \min \{ \}, \min \{ \gamma \} \} \} \] 
for all \( z = x \oplus y \);

(F2a) \( x, y \in F[\alpha] \) implies \((-x), y \in q_{\delta} F[\alpha] \);

(F3a) \( x, y \in F[\alpha] \) implies \((y \alpha x), y \in q_{\delta} F[\alpha] \) (resp., \((x \alpha y), y \in q_{\delta} F[\alpha] \);

(F4a) \( x, y \in F[\alpha] \) implies \( z, y \in q_{\delta} F[\alpha] \) for all \( z = -y \oplus x \oplus y \).

A fuzzy soft set \((\bar{F}, A)\) of \( R \) is called an 
\((e_{\alpha}, e_{\gamma}, q_{\delta})\)-fuzzy soft \( \alpha \)-hyperideal of \( R \) if it is both an 
\((e_{\alpha}, e_{\gamma}, q_{\delta})\)-fuzzy soft left and an \((e_{\alpha}, e_{\gamma}, q_{\delta})\)-fuzzy soft right \( \alpha \)-hyperideal of \( R \).

**Example 3.** Let \( R = \Gamma = \{0,1,2\} \) be two canonical hypergroups with hyperoperation \( \oplus \) as follows:

\[
\begin{array}{|c|c|c|c|}
\hline
\oplus & 0 & 1 & 2 \\
\hline
0 & 0 & 1 & 2 \\
1 & 0 & 1 & R \\
2 & 1 & 1 & R \\
R & 2 & R & 2 \\
\hline
\end{array}
\]

Define a mapping \( R \times \Gamma \times R \to R \) \( a \gamma b = a \cdot \gamma \cdot b \) by a
for all \( a, b \in R \) and \( \gamma \in \Gamma \), where \( \cdot \) is the following multiplication.

\[
\begin{array}{|c|c|c|c|}
\hline
\cdot & 0 & 1 & 2 \\
\hline
0 & 0 & 0 & 0 \\
1 & 0 & 1 & 2 \\
2 & 1 & 1 & R \\
R & 2 & R & 2 \\
\hline
\end{array}
\]

So it can be easily verified that \((R, \oplus, \Gamma)\) is a \( \Gamma \)-hyperring.

Let \( E = \{e_{\alpha}, e_{\gamma}\} \) be a set of parameters. Define a 
fuzzy soft set \((\bar{F}, E)\) over \( R \) by

\[
\bar{F}(e_{\alpha}) = 0.6 + 0.7 + 0.3 = 2
\]

and

\[
\bar{F}(e_{\gamma}) = 0.5 + 0.5 + 0.3 = 2
\]

Then \((\bar{F}, E)\) is an \((e_{0.3}, e_{0.3}, q_{0.3})\)-fuzzy soft \( \Gamma \)-hyperideal of \( R \).

**Lemma 4.2.** Let \((\bar{F}, A)\) be a fuzzy soft set over \( R \).
Then (F1a) holds if and only if one of the following conditions hold: for all \( \alpha \in A \) and \( x, y \in R \),

\[
\max \{ \inf_{z \in A}[F[\alpha](z), \gamma] \} \leq \min \{ \bar{F}[\alpha](x), \bar{F}[\alpha](y) \}
\]

**Proof:** (F1a) \( \implies \) (F1b) Let \( \alpha \in A \) and \( x, y \in R \). Suppose if possible that \( z \in H \) be such that 
\( z = x \oplus y \) and 
\( \max \{ \bar{F}[\alpha](z), \gamma \} < r = \min \{ \bar{F}[\alpha](x), \bar{F}[\alpha](y) \} \).
Then \( \bar{F}[\alpha](x) \geq r, \bar{F}[\alpha](y) \geq r, \bar{F}[\alpha](z) < r \leq \delta \),

hence, \( x, y, z \in F[\alpha] \) and \( z \in q_{\delta} F[\alpha] \), a contradiction. Hence (F1b) is valid.

(F1b) \( \implies \) (F1c) Let \( \alpha \in A, r \in (\gamma, 1] \) and \( x \in R \) be
such that \( x, e_{\gamma} \in F[\alpha] \) and \( z, e_{\gamma} \in q_{\delta} F[\alpha] \),

then it follows from \( \bar{F}[\alpha](x) < \delta \) that

\[
\max \{ \bar{F}[\alpha](x), \gamma \} \leq \min \{ \bar{F}[\alpha](y), \bar{F}[\alpha](z) \}
\]

Hence we have

\[
r < \min \{ \bar{F}[\alpha](a), \bar{F}[\alpha](b) \} \leq \sup \{ \max \{ \bar{F}[\alpha](x), \gamma \} \}
\]

a contradiction. Hence (F1c) is satisfied.

(F1c) \( \implies \) (F1a) Let \( \alpha \in A, r, s \in (\gamma, 1] \) and \( x, y \in R \), be such that \( x, y, z \in F[\alpha] \). Then for any \( z \in x \oplus y \), we have,

\[
(\bar{F} \oplus \bar{F})(z) = \sup_{x \in A} \min \{ \bar{F}[\alpha](a), \bar{F}[\alpha](b) \}
\]

Hence

\[
z_{\min_{\gamma}} \leq q_{\delta} \bar{F}[\alpha] \]

and so

\[
z_{\min_{\gamma}} \leq q_{\delta} \bar{F}[\alpha] \]
by (F1c). Hence (F1a) holds.

For any fuzzy soft set \((\overline{F}, A)\) over \(R\), denote by \((\overline{F}^{-1}, A)\) the fuzzy soft set defined by \(\overline{F}^{-1}[\alpha](x) = \overline{F}[\alpha](-x)\) for all \(\alpha \in A\) and \(x \in R\).

**Lemma 4.3.** Let \((\overline{F}, A)\) be a fuzzy soft set over \(R\). Then (F2a) holds if and only if one of the following conditions hold: for all \(\alpha \in A\) and \(x, y \in R\),

\[
(F2b) \quad \max \{ \overline{F}[\alpha](x), y \} \geq \min \{ \overline{F}[\alpha](x), y \}.
\]

**Proof:** It is similar to the proof of Lemma 4.2.

**Lemma 4.4.** Let \((\overline{F}, A)\) be a fuzzy soft set over \(R\). Then (F3a) hold if and only if one of the following conditions hold: for all \(\alpha \in A\) and \(x, y \in R\),

\[
(F3a) \quad \max \{ \overline{F}[\alpha](x), y \} \geq \min \{ \overline{F}[\alpha](x), y \}.
\]

**Proof:** It is similar to the proof of Lemma 4.2.

**Lemma 4.5.** Let \((\overline{F}, A)\) be a fuzzy soft set over \(R\). Then (F4a) holds if and only if one of the following conditions hold: for all \(\alpha \in A\) and \(x, y \in R\),

\[
(F4a) \quad \max \{ \inf \{ \overline{F}[\alpha](z), y \} \geq \min \{ \overline{F}[\alpha](x), y \}.
\]

**Proof:** It is similar to the proof of Lemma 4.2.

From the above discussion, we can immediately get the following two theorems:

**Theorem 4.6.** A fuzzy soft set \((\overline{F}, A)\) over \(R\) is an \((\in, \in, \vee, q_{\delta})\)-fuzzy soft\(\Gamma\)-hyperideal of \(R\) if and only if it satisfies (F1b), (F2b), (F3b) and (F4b).

**Theorem 4.7.** A fuzzy soft set \((\overline{F}, A)\) over \(R\) is an \((\in, \in, \vee, q_{\delta})\)-fuzzy soft\(\Gamma\)-hyperideal of \(R\) if and only if it satisfies (F1c), (F2c), (F3c) and (F4c).

For any fuzzy soft set \((\overline{F}, A)\) over \(R\), \(\alpha \in A\) and \(\gamma \in [0,1]\), we define

\[
\overline{F}(\alpha) = \{ x \in R \mid x \in \gamma \overline{F}[\alpha] \},
\]

\[
\overline{F}[\alpha]^{\gamma} = \{ x \in R \mid x, q_{\delta} \overline{F}[\alpha] \},
\]

and \([\overline{F}[\alpha]]^{\gamma} = \{ x \in R \mid x, \in q \overline{F}[\alpha] \}.
\]

It is clear that

\[
[\overline{F}[\alpha]]^{\gamma} = [\overline{F}[\alpha]^{\gamma} \cup \overline{F}[\alpha]]^{\gamma}.
\]

The next theorem provides the relationships between \((\epsilon, \epsilon, \vee, q_{\delta})\)-fuzzy soft\(\Gamma\)-hyperideal of \(R\) and crisp \(\Gamma\)-hyperideals of \(R\).

**Theorem 4.8.** Let \((\overline{F}, A)\) be a fuzzy soft set over \(R\). Then

1. \((\overline{F}, A)\) is an \((\epsilon, \epsilon, \vee, q_{\delta})\)-fuzzy soft \(\Gamma\)-hyperideal of \(R\) if and only if non-empty set \([\overline{F}[\alpha]]^{\gamma}\) is a \(\Gamma\)-hyperideal of \(R\) for all \(\alpha \in A\) and \(r \in (\gamma, \delta]\).

2. If \(2\delta = 1 + \gamma\), then \((\overline{F}, A)\) is an \((\epsilon, \epsilon, \vee, q_{\delta})\)-fuzzy soft\(\Gamma\)-hyperideal of \(R\) and non-empty set \([\overline{F}[\alpha]]^{\gamma}\) is a \(\Gamma\)-hyperideals of \(R\) for all \(\alpha \in A\) and \(r \in (\delta, 1]\).

3. If \(2\delta = 1 + \gamma\), then \((\overline{F}, A)\) is an \((\epsilon, \epsilon, \vee, q_{\delta})\)-fuzzy soft\(\Gamma\)-hyperideal of \(R\) and non-empty set \([\overline{F}[\alpha]]^{\gamma}\) is a \(\Gamma\)-hyperideals of \(R\) for all \(\alpha \in A\) and \(r \in (\delta, 1]\).

**Proof:** We only show (3). The proofs of (1) and (2) are similar. Let \((\overline{F}, A)\) be an \((\epsilon, \epsilon, \vee, q_{\delta})\)-fuzzy soft \(\Gamma\)-hyperideal of \(R\) and \(x, y \in \overline{F}[\alpha]^{\gamma}\) for some \(\alpha \in A\) and \(r \in (\delta, 1]\)

Then \(x_{\gamma} \in \gamma \overline{F}[\alpha]\) and \(y_{\gamma} \in \gamma \overline{F}[\alpha]^{\gamma}\), i.e., \(\overline{F}[\alpha](x) \geq r\) or \(\overline{F}[\alpha](x) \geq 2\delta - r \geq 2\delta - 1 = \gamma\), and \(\overline{F}[\alpha](y) \geq r \) or \(\overline{F}[\alpha](y) \geq 2\delta - 1 = \gamma\).

Since \((\overline{F}, A)\) is an \((\epsilon, \epsilon, \vee, q_{\delta})\)-fuzzy soft\(\Gamma\)-hyperideal of \(R\) and \(\min \{ \overline{F}[\alpha](x), \overline{F}[\alpha](y) \} \geq r\),
we have $\overline{F}(a)(z) \geq \min \{\overline{F}(a)(x), \overline{F}(a)(y), \delta\}$ for all $z \in x \oplus y$. We consider the following cases:

**Case 1:** $r \in (\gamma, \delta)$. Since $r \in (\gamma, \delta)$, we have $2\delta \geq \delta \geq r$.

**Case 1a:** $\overline{F}(a)(x) \geq r$ or $\overline{F}(a)(y) \geq r$.

Then $\overline{F}(a)(z) \geq \min \{\overline{F}(a)(x), \overline{F}(a)(y), \delta\} \geq r$.

Hence $z' \in \gamma \overline{F}(a)$.

**Case 1b:** $\overline{F}(a)(x) \geq 2\delta - r$ and $\overline{F}(a)(y) \geq 2\delta - r$.

Then $\overline{F}(a)(z) \geq \min \{\overline{F}(a)(x), \overline{F}(a)(y), \delta\} = \delta$ and so $f(z) + r \geq r + \delta > 2\delta$.

Hence $z, q \overline{F}(a)$.

**Case 2a:** $r \in (\delta, 1]$. Since $r \in (\delta, 1]$, we have $2\delta - r < \delta < r$.

Then $\overline{F}(a)(x) \geq r$ and $\overline{F}(a)(y) \geq r$.

Hence $z, q \overline{F}(a)$.

**Case 2b:** $\overline{F}(a)(x) > 2\delta - r$ or $\overline{F}(a)(y) > 2\delta - r$.

Then $\overline{F}(a)(z) \geq \min \{\overline{F}(a)(x), \overline{F}(a)(y), \delta\} > 2\delta - r$.

Hence $z, q \overline{F}(a)$. Thus in any case, $z, q \in q \overline{F}(a)$, i.e., $z \in \overline{F}(a)(\delta)$ for all $z \in x \oplus y$. Similarly we can show that the other conditions hold.

Therefore, $\overline{F}(a)(\delta)$ is an $\alpha$-hyperideal of $R$.

Conversely, assume that the given condition holds. Let $\alpha \in A$ and $x, y \in R$. If there exists $z \in R$ such that $z \in x \oplus y$ and

$\max \{\overline{F}(a)(z), \gamma\} \leq r = \min \{\overline{F}(a)(x), \overline{F}(a)(y), \delta\}$,

then $\overline{F}(a)(x) \geq r$, $\overline{F}(a)(y) \geq r$, $\overline{F}(a)(z) \leq \delta$,

i.e., $x, y \in \overline{F}(a)$ but $z \not\in q \overline{F}(a)$. Hence $x, y \in \overline{F}(a)(\delta)$, a contradiction. Therefore, $\max \{\overline{F}(a)(z), \gamma\} \geq \min \{\overline{F}(a)(x), \overline{F}(a)(y), \delta\}$ for all $z \in x \oplus y$. This proves (F1c) holds.

Similarly we can show that (F2b), (F3b) and (F4b) hold. Therefore $(\overline{F}, A)$ is an $(\epsilon, \epsilon\gamma\cup q\delta)$-fuzzy soft $\Gamma$-hyperideal of $R$ by Theorem 4.7.

**Remark 4.9.** For any $(\in, \in\vee q\delta)$-fuzzy soft $\Gamma$-hyperideal of $R$, we can conclude that

1. $(\overline{F}, A)$ is an $(\in, \in\vee q\delta)$-fuzzy soft $\Gamma$-hyperideal of $R$, for all $\alpha \in A$. When $\gamma = 0$ and $\delta = 1$ (see[51]);

2. $(\overline{F}, A)$ is an $(\in, \in\vee q\delta)$-fuzzy soft $\Gamma$-hyperideal of $R$. When $\gamma = 0$, $\delta = 0.5$.

**Theorem 4.10.** Let $(\overline{F}, A)$ and $(\overline{G}, B)$ be two $(\epsilon, \epsilon\gamma\cup q\delta)$-fuzzy soft $\Gamma$-hyperideals of $R$.

Then $(\overline{F}, A) \oplus (\overline{G}, B)$ is an $(\epsilon, \epsilon\gamma\cup q\delta)$-fuzzy soft $\Gamma$-hyperideal of $R$ if and only if $(\overline{F}, A) \oplus (\overline{G}, B) = (\epsilon, \epsilon\gamma\cup q\delta)$.

**Proof:** If $(\overline{F}, A) \oplus (\overline{G}, B) = (\epsilon, \epsilon\gamma\cup q\delta)$, then

\[
(\overline{F}, A) \oplus ((\overline{G}, B) \oplus (\overline{F}, A)) = (\overline{G}, B) \oplus (\overline{F}, A) = (\overline{G}, B) \oplus (\overline{F}, A) = (\overline{G}, B) \oplus (\overline{F}, A).
\]

Hence $(\overline{F}, A) \oplus (\overline{G}, B) \oplus ((\overline{F}, A) \oplus (\overline{G}, B))$.

This proves that (F1c) holds.

Now for any $\alpha \in A \cup B$ and $x \in R$,

**Case 1.** $\alpha \in A - B$. Then

\[
\max \{\overline{F}(\overline{G})(\alpha)(-x), \gamma\} = \max \{\overline{F}(\alpha)(-x), \gamma\} \geq \min \{\overline{F}(\alpha)(x), \delta\} = \min \{\overline{F}(\overline{G})(\alpha)(x), \delta\}
\]

**Case 2.** $\alpha \in B - A$. Analogous to case 1, we have

\[
\max \{\overline{F}(\overline{G})(\alpha)(-x), \gamma\} \geq \min \{\overline{F}(\alpha)(x), \delta\}
\]

**Case 3.** $\alpha \in B \cap A$.

\[
\max \{\overline{F}(\overline{G})(\alpha)(-x), \gamma\} = \max \{\sup \min \overline{F}(\alpha)(a), \overline{G}(\alpha)(b), \gamma\}
\]
Let \((\widetilde{F}, A)\) be an \((\varepsilon, \varepsilon \vee \eta q)\)-fuzzy soft \(\Gamma\)-hyperideal of \(R\), then \((\widetilde{F}, A) \oplus (\overline{G}, B)\) is an \((\varepsilon, \varepsilon \vee \eta q\delta)\)-fuzzy soft \(\Gamma\)-hyperideal of \(R\). Thus, in any case, we have

\[ (\widetilde{F}, A) \cap (\overline{G}, B) = (\overline{G} \cap \overline{F})(\alpha), \delta \]
From \((\overline{F},A) \otimes (\overline{F},A) \subseteq \vee q_{\mathcal{A},\mathcal{A}}(\overline{F},A)\), we have
\((\pi, A) \otimes (\overline{F},A) \otimes (\overline{F},A) \subseteq \vee q_{\mathcal{A},\mathcal{A},\mathcal{A}}(\pi, A)\), and so
\[
\min \{(\pi \oplus \overline{F})[a](y), \delta\}
\geq \min \{(\pi \oplus F)[a](y), \delta\}
\geq \min \{(\pi \oplus F)[a](y), \delta\}
= \min \\sup_{y \in R} \{(\pi \oplus F)[a](y), \delta\}
\geq \min \{(\pi \oplus F)[a](z), \delta\} > r.
\]
It follows that \(\min \{(\pi \oplus F)[a](z), \delta\} > r\) since \(r \geq \gamma\), i.e., \(x \overline{F}[a] \in z\). Hence \(\overline{F}[a]\) is transitive.

Summing the above arguments, \(\overline{F}[a]\) is an equivalence relation on \(R\). Next let \(x, y, z, a \in R\) be such that \(x \overline{F}[a] y\) and \(a \in x \oplus z\). Then \(\min \{(\pi \oplus F)[a](x), \delta\} > r\).

From Proposition 4.11, we have
\[
\min \{(y \otimes z) \oplus \overline{F}[a](y), \delta\}
\geq \min \{(y \otimes \pi \oplus F)[a](y), \delta\}
\geq \min \{(y \otimes \pi \oplus F)[a](y), \delta\}
= \min \\sup_{y \in R} \{(y \otimes \pi \oplus F)[a](y), \delta\}
\geq \min \{(y \otimes F)[a](x), (x \otimes \pi \oplus F)[a](x), \delta\}
= \min \{(y \otimes \pi \oplus F)[a](x), (x \otimes \pi \oplus F)[a](x), \delta\} > r.
\]
Hence there exists \(c \in R\) such that \(c \in y \otimes z\) and \(\min \{(y \otimes \pi \oplus F)[a](y), \delta\} > r\), i.e.,
\(a \overline{F}[a] c\). Similarly, if \(d \in y \otimes z\) for some \(d \in R\), then there exists \(e \in R\) such that \(d \in x \oplus z\) and \(d \overline{F}[a] e\). Hence \(x \oplus z \overline{F}[a] x \oplus y\). In a similar way, we have \(z \oplus x \overline{F}[a] z \oplus y\). Finally, let \(x, y, z \in R\) and \(a \in \Gamma\) be such that \(x \overline{F}[a] y\). Then \(\min \{(y \otimes F)[a](x), \delta\} > r\).

From Proposition 4.11, we have
\[
\min \{(\pi \oplus F)[a](x), \delta\}
= \min \\sup_{y \in R} \{(\pi \oplus F)[a](x), \delta\}
= \min \\sup_{y \in R} \{(\pi \oplus F)[a](x), \delta\} > r
\]
and so,
\[
\min \{(zax)_i \oplus \overline{F}[a](zax), \delta\}
= \min \\sup \min \{\overline{F}[a](a), \delta\}
= \min \{\overline{F}[a](zab), \delta\}
= \min \{\min \{\overline{F}[a](b), \delta\}, \delta\} > r
\]
that is, \(zaz \overline{F}[a] zax\). In a similar way, we have \(xaz \overline{F}[a] yaz\). Therefore, \(\overline{F}[a]\) is a congruence relation on \(R\). This completes the proof.

Let \(\overline{F}[a]\) be the equivalence class containing the element \(x\). We denote by \(R / \overline{F}[a]\) the set of all equivalence classes, i.e., \(R / \overline{F}[a] = \{\overline{F}[a] x | x \in R\}\). Since \(\overline{F}[a]\) is a congruence relation on \(R\), we can easily deduce the following theorem.

**Theorem 4.14.** Let \((\overline{F},A)\) be an \((\epsilon_\mathcal{A}, \epsilon_\mathcal{A}, \vee q_{\mathcal{A}})\)-fuzzy soft \(\Gamma\)-hyperideal of \(R\), \(a \in A\) and \(r \in [\gamma, \min \{\overline{F}[a](0), \delta\}]\). Then \((R / \overline{F}[a], \oplus, \Gamma)\) is a \(\Gamma\)-hyperideal with respect to the hyperoperation \(\oplus\) and the operation \(\oplus\):
\[
\overline{F}[a] x \oplus \overline{F}[a] y = \overline{F}[a] x \oplus y \quad \text{for all } x, y \in R \text{ and } a \in \Gamma.
\]

**5. Conclusion**

In this paper, we consider the \((\epsilon_\mathcal{A}, \epsilon_\mathcal{A}, \vee q_{\mathcal{A}})\)-fuzzy soft \(\Gamma\)-hyperideal of \(\Gamma\)-hyperideal. In particular, we obtain a kind of new \(\Gamma\)-hyperideal by congruence relations. In our future study of fuzzy structure of \(\Gamma\)-hyperideal, the following topics could be considered:
1. To consider the \((m,n)\)-\(\Gamma\)-hyperideals;
2. To establish three (fuzzy) isomorphism theorems of \((m,n)\)-\(\Gamma\)-hyperideals;
3. To describe the fuzzy soft \((m,n)\)-\(\Gamma\)-hyperideals and their applications.

**Acknowledgements**

This research is partially supported by a grant of Natural Innovation Term of Higher Education of Hubei Province, China, # T201109.


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